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THE NATURE AND ORIGIN OF COMETS AND METEORS

by S. K. Vsekhsvyatskiy

"Prosveshcheniye" Press, Moscow, 1967

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • APRIL 1970

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THE NATURE AND ORIGIN OF COMETS AND METEORS

By S. K. Vsekhsvyatskiy

Translation of: "Priroda i Proiskhozhdeniye
Komet i Meteornogo Veshchestva"
"Prosveshcheniye" Press, Moscow, 1967

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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The contemporary problems concerning comets, the characteristics of their movement and their physical nature are discussed in this book. Particular attention is given to the problems of the evolution and origination of comets. For the first time, proofs that comets are related to other groups of small bodies are presented in expanded form; justifications of the disruption theory are given and important practical and theoretical results of modern cometary cosmogony are formulated.

THE NATURE AND ORIGIN OF COMETS AND METEORS

S.K. Vsekhsvyatskiy

TABLE OF CONTENTS

PREFACE..... iv
INTRODUCTION..... v

PART I. COMETS AND OTHER GROUPS OF SMALL BODIES..... 1

1. A Brief Review of the History of Cometary Astronomy..... 1
2. The Number of Comets and Their Movements. Characteristics of the System of Comets..... 3
3. Comparison With Other Groups of Small Bodies..... 11
4. Comet Discoveries. Recent Comets..... 18
5. Phenomena in the Heads and Tails of Comets; Fundamentals of the Mechanical Theory of Comets..... 31
6. Brightness and Absolute Magnitudes of Comets..... 39
7. The Spectra of Comets and the Nature of the Parent Matter.. 45
8. The Ice in Cometary Nuclei..... 50

PART II. THE ORIGIN OF COMETS..... 55

9. Contemporary Theories and Their Correspondence With the Data on the Motion and Nature of Comets..... 55
10. The Laplace Problem..... 59
11. Statistics of Aphelion or Perihelion Directions..... 69
12. Oort's Hypothesis of a Cloud of Comets..... 73
13. Short-Period Comets; the Capture Problem..... 77
14. The Probability of Transformations of Orbits and the Theoretical Number of Comets with Different Periods..... 83
15. Absolute Magnitudes and Disintegration of Short-Period and Periodic Comets..... 91

PART III. DISRUPTION THEORY AND THE PROBLEMS OF THE SOLAR SYSTEM..... 99

16. Facts on Comets in the Life of a Planetary Vulcanism..... 99
17. Distribution of Orbital Elements in the Disruption Theory..105
18. The Scales of Processes on Jupiter's Satellites.....113
19. Small Bodies. The Nature of the Processes on Planets and the Disruption Theory.....122
20. An Estimate of the Number of Comets Formed in the Solar System.....136
21. Additional Proof of the Eruptive Origin of Comets and Meteoric Matter; New Problems.....141
22. Scales of Vulcanism on the Earth and Geological Problems...154

APPENDIX.....161
References.....175

DEDICATED TO THE MEMORY OF THE
PIONEERS OF THE DISRUPTION THEORY:

Joseph Lagrange
Henrich Olbers
Richard Proctor
Andrew Crommelin
Aleksey Petrovich Pavlov
Vladimir Nikolayevich Lodochnikov

PREFACE

The problems connected with the nature and origin of comets are discussed in this book by the most prominent Soviet specialist on the problems of cometary astronomy, Professor S.K. Vsekhsvyatskiy. The author is a great expert on the facts relating to comets, and has developed a daring hypothesis on the origin of comets which has played a very important role. The short life span of short-period comets and the characteristics of their movement have made it urgently necessary to explain the sources of their arisal. At the same time, the old hypotheses on the origin of short-period comets by way of capture have encountered great difficulties. Although we cannot always agree with some of the extreme statements found in the theory presented by the author, we nevertheless must say that the author's opinions merit most serious attention and discussion.

The author is working on the most complex problems of the nature of comets with the enthusiasm of a real scientist, and many of his results have long become the common property of astronomers.

This book will therefore be read with great interest.

Academician V. Ambartsumyan

INTRODUCTION

The increasingly rapid acquisition of scientific knowledge during the last few decades has brought us to the era of a new and great revolution in natural science. The tremendous discoveries in the solar system, the Galaxy and the Metagalaxy which are connected with the achievements of the physics of atoms and elementary particles, the development of radio-astronomy methods and electronic astronomy techniques, with the fine successes in the mastery of outer space, not only have raised new problems in physics, which is converting from terrestrial to cosmic physics, but also have opened new horizons in the study of cosmic processes.

The revolutionary reorganization should first affect the principal problems of the solar system and bring about a change in numerous widely-accepted theories.

Therefore, the time has come to present the results of exhaustive investigations of comets and other groups of small bodies of the solar system in a systematic form. These investigations have already shown the groundlessness and errors of many widely-acknowledged ideas in cosmogony.

The book is entitled "Nature and Origin of Comets and Meteors". However, it contains a systematic presentation and development of the disruption idea formulated and defended by Olbers, Lagrange, Proctor, Crommelin and other thinkers; therefore, it concerns not only the problems of small bodies but also the most fundamental problems of planets and the solar system.

The conclusions of the disruption theory necessitate a re-examination of the principal ideas of planetology, geophysics and geology, as well as a new consideration of the ideas of Cuvier, Humboldt and other representatives of catastrophism, in order to explain the actual history of the solar system.

The author would like to express his heart-felt thanks to Yelena Ivanovna Vsekhsvyatskaya, a friend and companion in life and in troubles, as well as his students V.I. Ivanchuk, G.A. Rubo, V.I. Cherednichenko and D.A. Andriyenko, who examined some sections of the manuscript, for their criticisms.

Professor S.K. Vsekhsvyatskiy

PART I

COMETS AND OTHER GROUPS OF SMALL BODIES

1. A Brief Review of the History of Cometary Astronomy

The appearence of bright comets with tails often extending /5*
tens of degrees and even throughout the entire night sky has attracted general attention since antiquity and, in the majority of cases, has roused superstitious fears.

Fortunately for science, the information on appearances of comets was preserved in the remote past in Chinese and Japanese chronicles, as well as in historic memorials of African, Central Asian and European nations; in addition to solar and lunar eclipses and the flights of bright bolides, Chinese astronomers also remarked on the appearance of comets. The encyclopedias of She-Ke, Ma Tuan Min and Tun Kin Kan Muh, which contain observations of comets from B.C. to primarily the first and second millenia of this era, have been preserved. Extracts from these chronicles were published in the studies of E. Biot and D. Williams. Even earlier information was collected in the cometography of A. Pingre. Data on comets were also drawn from Japanese chronicles, from the manuscripts of the peoples of Europe and, in particular, from Russian manuscripts.

The "General Catalogue of Comets before 1948", which was constructed by F. Baldet on the basis of an analysis of all the data compiled twenty years ago, is very interesting material on the history of cometary astronomy. The list begins with the legendary comet "Potop"; 17 comets were noted from 2315 to 1000 B.C. (according to Chinese, Egyptian, Chaldean, Assyrian and Elamite witnesses). In one millenium (from 1000 B.C. to 0 A.D.), 117 comets were mentioned, mainly by Chinese, Greek and Roman observers; in the following millenium (to 1000 A.D.), 337 comets are mentioned in the list of Baldet, and the total is 1619 comets (to 1949). The majority of these comets were not observed with sufficient care: it was impossible for the observers to determine the orbits, and they were not entered in the catalogue of cometary orbits, which contains (before 1949) data on 735 appearances.

The first precise determinations of the positions of Comet 1472 in the sky were made by Regiomontanus in Nurenburg. These observations showed that the comet was more distant than the Moon, "in the region of the planets", and therefore could not be an atmospheric phenomenon. Some decades later, P. Apian found that the tails of all the comets he observed were directed away from the Sun. Many

* Numbers in the margin indicate pagination in the foreign text.

centuries before then, Chinese astronomers had noted the same characteristic feature in the comets. /6

In the second half of the 16th century, the accurate observations of Tycho Brahe and some other astronomers raised the question of the nature of the movement of comets. In a treatise on Comet 1607, Kepler attributed a rectilinear motion to it; Hevelius (1665) considered the paths of comets to be slightly curving; George Derffel suggested that comets move along parabolas, with the Sun at the focus. Isaac Newton showed (1687) that many comets move along parabolic paths, and he found a method of determining the orbits. Edmund Halley, who used Newton's method, determined (1705) the orbits for 24 comets and found among them three practically identical orbits belonging to different appearances of the first periodic comet, which was given Halley's name. In 1776, the Petersburg astronomer Lexell found that the period for the return of Comet 1770, which was discovered by Messier, was equal to 6 years, and he showed that short-period comets existed. These discoveries created great interest in calculating cometary orbits and the development of the theory of their motion. It was later established that short-period comets make up a large portion of all the discovered comets.

The achievements in the field of cometary calculations and the development of new methods for determining the orbits furthered the idea of an analysis of all the previous cometary observations and a clarification of the characteristics of comet systems.

At the beginning of the 19th century, Laplace and Lagrange almost simultaneously proposed directly opposing hypotheses on the origin of comets, thus originating cometary cosmogony. Laplace suggested that the comets come from interstellar space and that planetary perturbations, and possibly the resistance of the medium, transform some cometary orbits into elliptical ones. Lagrange proposed the idea of eruptions on planets and ejections of cometary matter into interplanetary space.

The sympathies of 19th-century astronomers were on Laplace's side, and the problem he formulated was the object of numerous investigations for more than 150 years. Lagrange's hypothesis met no response and was forgotten.

Brandes and Olbers made the first steps to explain the characteristics of comets and their tails; they found approximate values for the repulsive forces of the Sun acting on particles of the tails. F. Bessel formulated basic positions of the mechanical theory of cometary forms in a study on the appearance of Halley's Comet in 1835, and he gave a method of approximating calculations. F.A. Bredikhin developed new trends in the mechanical theory of the tails of comets, discovering important characteristcs of cometary phenomena.

Donati first observed the spectrum of a comet in 1864. Photography showed fine details in the structure of comets, raising new problems for the mechanical theory; these problems were resolved successfully by the students of Bredikhn: A.P. Sokolov, R. Yegerman, K.D. Pokrovskiy and others. New methods in the mechanical theory were developed at the beginning of the 20th century by A.Ya. Orlov, S.V. Orlov and students of the late N.D. Moiseyev, B.A. Vorontsov-Vel'yaminov and others. New results were obtained by N.Bobrovnikoff (USA). /7

The nature of the processes in comets was clarified substantially by a study of the brightness of comets and its variation with the heliocentric distance, as a result of investigations of the spectra of comets and the structure of their tails, as well as the development of spectrophotometric investigations since the beginning of the 50's.

Modern cometary photometry was begun by I. Golechek, A. Fowler, F. Hogg, F. Baldet, N. Bobrovnikoff, S.V. Orlov, P. Swings, K. Wurm and others lay the foundations for modern physicochemistry of comets as a result of investigations of the spectra of comets.

In 1930-1931, S.K. Vsekhsvyatskiy found a rapid decrease in the absolute brightness of short-period comets and developed the disruption theory on a new basis, reviving Lagrange's idea.

In 1948-1950, the existence of methane-ammonium ice in the nuclei of comets (S.K. Vsekhsvyatskiy, P. Swings, F. Whipple) was established, and the model of "contaminated ice" (F. Whipple) was developed. The problems of the structure of cometary nuclei and the physical conditions in the heads of comets underwent detailed discussions in this regard (B.A. Vorontsov-Vel'yaminov, O.V. Dobrovol'skiy, etc.).

In 1950-1960, many characteristics of comets were found to be indicators of solar effects in interplanetary space, and cometary investigations were included in the program of the International Year of the Quiet Sun on the initiative of Soviet astronomers.

2. The Number of Comets and Their Movements. Characteristics of the System of Comets

The modern characteristics of the system of comets are reflected from the point of view of their orbits in Porter's catalogue, together with the supplements of comets with known orbits, according to the status in 1966 [1]. This catalogue, as well as those of Crommelin (1925), Yamomoto (1936), Baldet and di Obaldia (1952), is based on the famous list by Galle [2], which also contains data on the observations which were used to derive the elements.

The final designation of the appearance is given in the cometary catalogues: it is designated by the year of the passage of the

comet through the perihelion and the index number (Roman numerals) depending on the data of the passage; for example, the last appearance of Halley's Comet is designated as 1910 II (the comet passed through perihelion on April 20, 1910); the elements characterizing the size and shape of the orbit are given (perihelion distance q, eccentricity e, return period P), as is its geometrical orientation (angle of inclination i, longitude of the ascending node Ω, argument of the perihelion ω).

The total number of appearances of comets with catalogued orbits reached 876 by 1966; these appearances relate to 582 independent comets. A statistical analysis of the cometary catalogues has been carried out by a number of researchers (Golechek, Herz, Watson, Richter). The most recent compilation, that of Porter [3], will be used in the future, with supplementary data on the comets up to 1966.

Of the total number of 876 appearances, 295 refer to "parabolic" comets, 65 had notable hyperbolic eccentricities, 123 corresponded to long-period comets (with period longer than 200 years), 43 corresponded to short-period comets with one appearance, and the remaining 350 were appearances of 55 short-period comets ($P < 200$ years) which were observed in two or more returns.

Porter gives the following table characterizing the increase in number of comets discovered:

TABLE 1

Epoch	New Parabolas	New Periodic	Precalculated and Rediscovered
1801—1840	41	7	11
1841—1880	99	17	33
1881—1920	106	31	58
1921—1960	116	35	124

It can be seen from the table that while the number of parabolic comets discovered increased three times, the number of discoveries of new periodic comets increased five times. This discrepancy in the rate of discoveries is an interesting problem which we will discuss later.

Examining the distributions of different orbital elements and the results of the statistics of the comets, we must keep in mind that the data of the cometary catalogues are not uniform or precise to the same extent. The accuracy of observations and the orbital comets based on them, which were found in the 19th century or even earlier, is much inferior to the accuracy of present knowledge of the orbits. Thanks to the increase in power of modern telescopes and the improvements in measuring techniques much weaker comets are being discovered, and the duration of their observations is being increased by a large factor. The accuracy of the elements,

which are now based on longer sections of the path of comets around the Sun, has also increased greatly. /9

The data of Table 1 also illustrate this well. If the ratio between the number of parabolic orbits and that of short-period orbits was about 6:1 in the 19th century (primarily parabolic orbits were obtained for the majority of the new comets), then it decreased to 3:1 in our time. Doubtless many past comets which have parabolic orbits in the catalogues actually had elliptical or hyperbolic orbits.

The conditions for the discovery of the comets, or the so-called visibility, also should affect the materials in cometary catalogues. After Copernicus, astronomy was developed primarily in the northern hemisphere of the Earth. The first observatories to carry out regular observations of celestial bodies and to survey the stellar sky were constructed here. In the southern hemisphere, the observatories numbered only a few. Only now have numerous observatories been constructed for studies of the southern sky. Therefore, it was primarily those comets which entered the sky of the northern hemisphere during the period of greatest brightness, i.e., in the perihelion, which were discovered in the 17th and 18th centuries.

The cometary catalogues clearly reflect these effects of the "visibility conditions", as I. Holetchek called them, being the first to call attention to these effects. The discovery of a comet ($q < 1$) is less probable if its perihelion longitude is close to the longitude of the Sun during the period of the passage of the comet through the perihelion. Obviously, even bright comets disappear during dawn in this regard. Holetchek's condition says that the number of comets which have small $L_\oplus - \lambda_p \pm 180° = \psi$ ($L_\oplus$ is the time of the passage through perihelion, expressed in terms of the longitude of the Earth, λ_p is the perihelion longitude) should be less than the number of comets with ψ close to 180°. This fact is illustrated well in Table 2, which was taken from Porter's study.

TABLE 2

$L_\oplus \pm 180°$	λ_p 90°	180°	270°	360°	Sum
279°— 10° (Jan-March)	28	38	27	19	112
10°— 98° (Apr-June)	17	24	43	28	112
98°—186° (July-Sept)	29	20	27	43	119
186°—279° (Oct-Dec)	38	35	22	33	128

Although the number of comets with a given time of passage through perihelion does not show any seasonal variation on the average, there is a clear function inside each season as the result of the effect of the sunrise cone. Comets with advantageous orbital distributions ($\psi \approx 180°$) are discovered roughly 2-2.5 times more /10

frequently than comets with $\psi \approx 0°$.

The conditions for discovery of comets, or the observational selection, also affect the characteristics of the distribution of perihelion distances q, semiaxes a and eccentricities e.

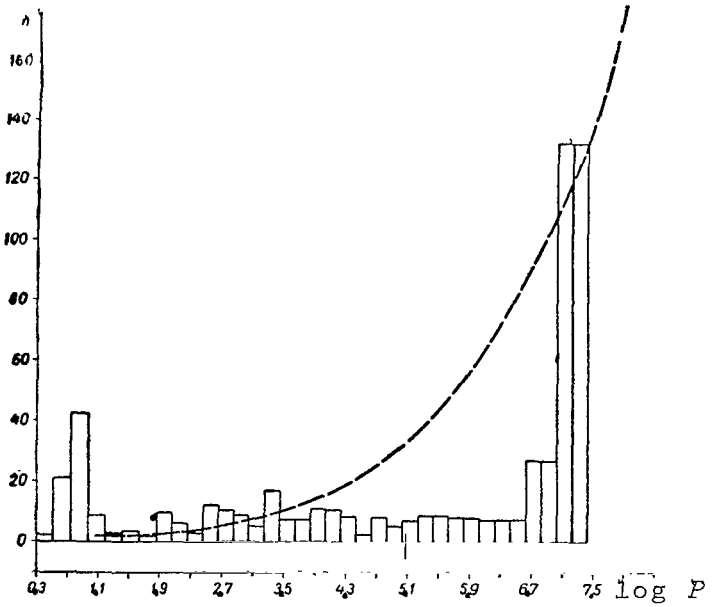

Fig. 1. Distribution of 577 Comets with Defined Orbits (Including the Beginning of 1965) by Logarithm of the Return Period log P. (The Dotted Line Shows the Theoretical Distribution.)

Comets with $q \approx 1$ or $q < 1$ have the greatest probability of being discovered, when they acquire substantial apparent brightness, passing rather near the Earth. Therefore, high eccentricity values will be found more often for long-period comets with great semiaxes, since $q = a(1-e)$.

The characteristics of the system of comets stand out in an examination of the distributions of numbers of comets as a function of a or, which is the same, as a function of P (since $P = a^{3/2}$).

Figure 1 shows the distributions of numbers of comets as a function of the value for the logarithm of the return period (log P). The numbers of comets marked off on the ordinate axis refer to intervals of 0.2 of log P.

A high maximum (for the value log P = 0.5 - 1.0), which corresponds to the Jupiter family of comets, can be seen in the figure. The subsequent maxima are for intervals of 1.9 - 2.0, 2.5 - 2.7 and 3.2 - 3.5. Their very existence shows that there are groups of comets, and that there is no uniform distribution, which is necessary for an equilibrium system. /11

Between the multiple group of Jupiter comets and the comets of the Neptune group ($P \approx 70$-100 years), there are comets of the Saturn and Uranus families, which show the same characteristic feature as the Jupiter or Neptune comets, although they are not singled out on the general distribution curve: the apheli of the orbits of comets in the same family are located in the vicinity of the orbit of the corresponding planet. This relationship shows up particularly clearly in the Jupiter family, and is obvious in the other families (Figs. 2 and 3).

Considering the grouping of comets by families, let us acquaint ourselves with another important characteristic of cometary orbits:

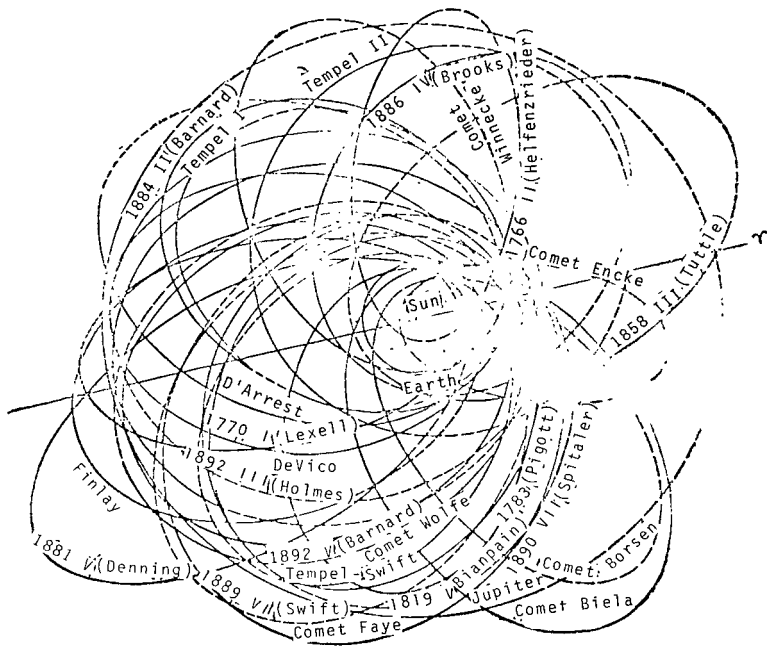

Fig. 2. Orbits of the First 28 Short-Period Comets of the Jupiter Family in Projection on the Plane of the Ecliptic.

the distribution of the angles of inclination of the orbits to the plane of the ecliptic (Fig. 4).

The distinguishing feature of the distribution of inclinations /12 is the purely planetary nature of the movement and the absence of retrograde motions for Jupiter's family of comets, as well as the predominance of straight-line motions near the ecliptical plane of the comets of Saturn and the regular transition to the maximum near $i = 90°$, which is characteristic of nearly parabolic comets.

In order to characterize the features of short-period comets of different families more completely, we will give the distributions for perihelion distances q (Fig. 5) and longitude of the ascending node Ω (Fig. 6)

Thirty-two years ago, in one of our studies[1], we made a comparison between systems of short-period comets and asteroids (Fig. 7). It is very interesting to compare these 1933 distributions to those of new objects.

[1] Astronomicheskiy Zhurnal, Vol. 11, No. 5, p. 43, 1934.

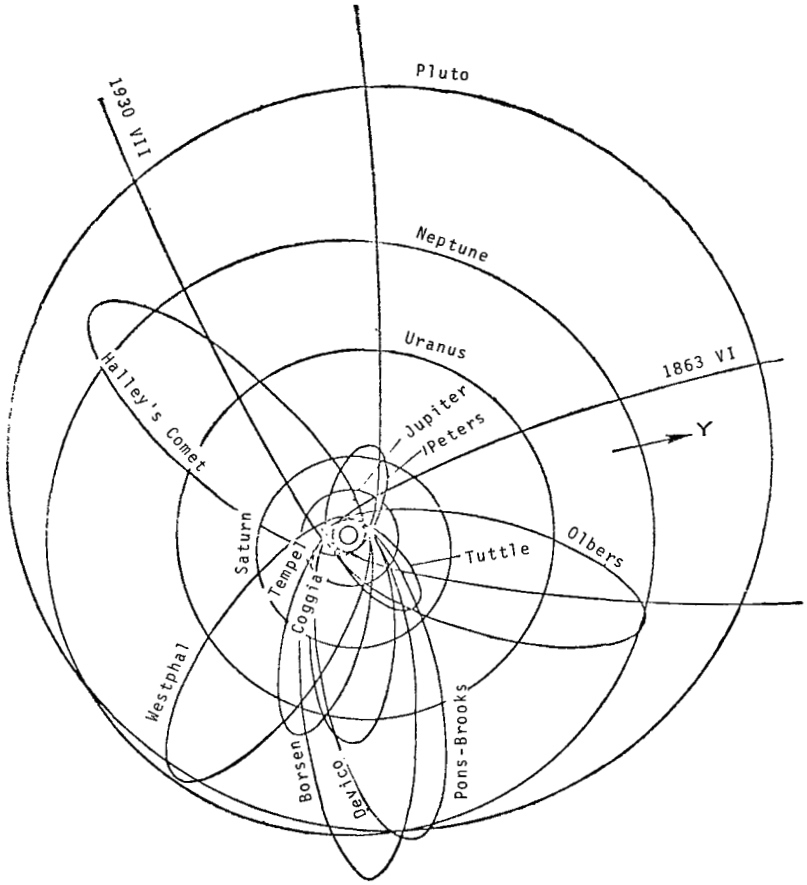

Fig. 3. Some Comets of the Families of Saturn, Uranus and Neptune.

The distribution of perihelion distances is given separately /13
for all the comets; by substracting the corresponding values, we can obtain an idea of the distributions of long-period and nearly parabolic comets.

The orbits of comets with parabolic perihelion eccentricities are not separated from the entire set of nearly parabolic comets.

In Table 3, we present a list of perihelion and initial values of $1/a$ for hyperbolic comets; it is based on the recent surveys of Porter and Galibina, as well as the basic text of Z. Sekanina [32].

The characteristic features of the distributions and the existence of families of short-period comets allow us to conclude that there is no stationary, equilibrious state in the system of comets. Short-period comets are easily distinguished from the set of long-period or nearly parabolic comets.

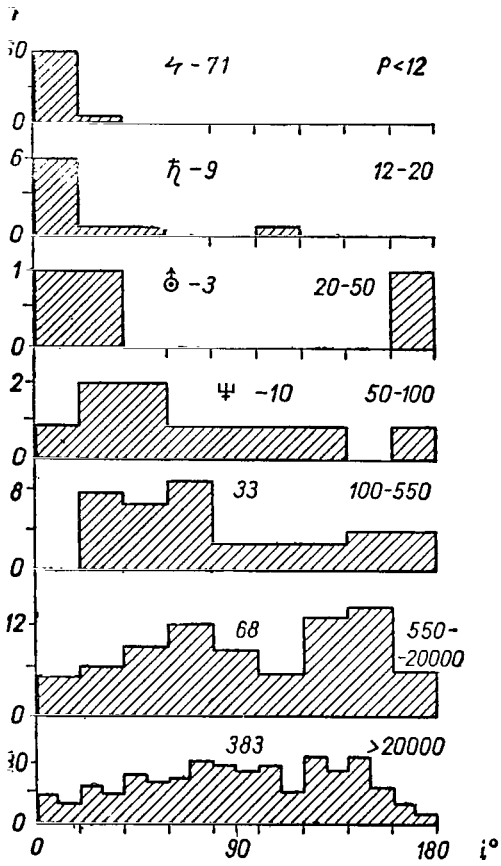

Fig. 4.

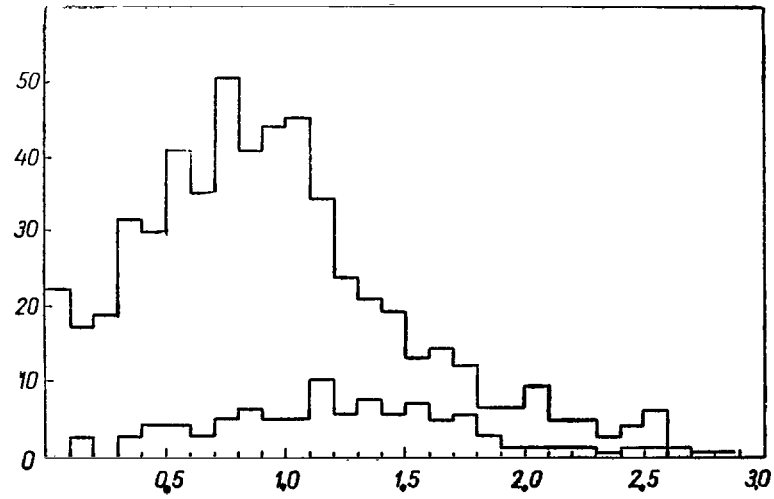

Fig. 5. Distribution of Nearly Parabolic Comets (Upper Curve) and Short-Period Comets by Perihelion Distances q.

Fig. 4. Distribution of 577 Comets by Angle of Inclination of the Orbits to the Ecliptic for Different Groups.

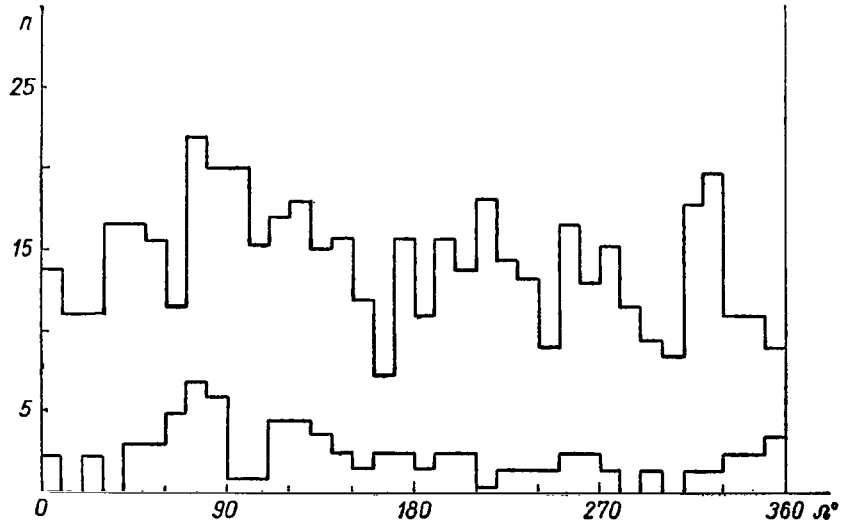

Fig. 6. Distribution by Longitude of Ascending Node Ω for all Comets (Upper Curve) and Short-Period Comets (Lower Curve).

/14

TABLE 3

/15

Comet	$\frac{1}{a}$ Perihelion, from Observations	$\frac{1}{a}$ Initial, on Entry into the Boundaries of the Planetary System
1853 III	−0,0008193	+0,0000829
1863 I	−0,000059	+0,000528
1863 VI	−0,0004949	+0,0000166
1880 II	−0,000463	+0,000511
1886 I	−0,0006944	−0,0000071
1886 II	−0,0004770	+0,0003166
1886 III	−0,015298	−0,014666(?)
1886 IX	−0,0005765	+0,0000630
1889 I	−0,0006915	+0,0000420
1890 II	−0,0002151	+0,0000718
1890 III	−0,002478	−0,002142
1892 II	−0,000175	+0,000845
1893 I	−0,001327	−0,000852
1896 I	−0,001101	−0,000273
1897 I	−0,0008722	+0,0000396
1898 VII	−0,0006074	−0,0000157
1899 I	−0,001073	−0,000123
1900 II	−0,000409	+0,000610
1904 I	−0,0005040	+0,0002165
1904 II	−0,000149	+0,000068
1905 IV	−0,000443	+0,000045
1905 V	−0,000180	+0,000265
1905 VI	−0,0001424	+0,0006210
1907 I	−0,0004991	+0,0000252
1908 III	−0,000732	+0,000161
1911 IV	−0,000561	−0,000157
1914 III	−0,000980	−0,000066
1914 V	−0,0001465	+0,0000119
1915 II	−0,000234	+0,000130
1919 V	−0,000193	+0,000013
1922 II	−0,0003806	+0,0000038
1925 I	−0,0005665	+0,0000540
1925 VI	−0,000464	+0,000073
1925 VII	−0,0002730	+0,0001150
1930 IV	−0,000182	+0,000525
1932 VI	−0,0005948	+0,0000441
1936 I	−0,0004870	+0,0002050
1937 IV	−0,000092	+0,000056
1941 VIII	−0,000279	+0,000083
1942 IV	−0,000618	+0,000261
1944 I	−0,003024	−0,00236
1944 IV	−0,000937	+0,000007
1946 I	−0,000697	−0,000024
1946 VI	−0,000699	+0,000044
1948 I	−0,000410	+0,000094
1950 I	−0,000267	+0,000241
1951 I	−0,000471	+0,000033
1954 V	−0,000337	+0,000142
1959 III	−0,002124	−0,000548
1960 II	−0,000570	−0,000108

/16

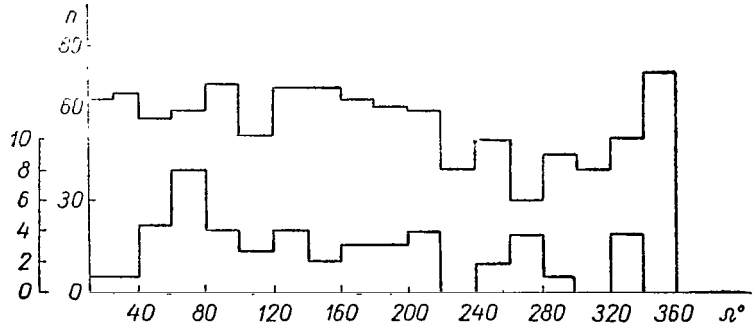

Fig. 7. Distribution of Ω for Asteroids and Short-Period Comets (1933).

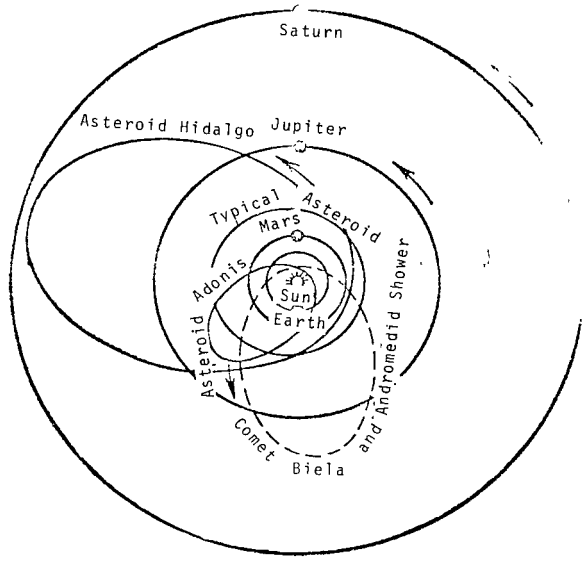

Fig. 8. Typical Orbit of Asteroid and Comet-Shaped Orbits of the Minor Planets Hidalgo and Adonis.

3. Comparison With Other Groups of Small Bodies

Figure 8 shows the orbits of some asteroids which have substantial similarity with the orbits of some famous comets (Encke, Wilson-Harrington, etc.). Asteroids of the Trojan group move along /17 orbits which are very similar to the paths of Comets Schwassmann-Wachmann1 and Oterma. The curve for the distribution of semiaxes of short-period comets overlaps the distribution for asteroids, while the distribution of eccentricities is a continuation of that for asteroids entering far into the cometary series (Figs. 9, 10).

A comparison of the inclinations of both systems is of no less interest. It can be seen from Figure 10 that the system of asteroids

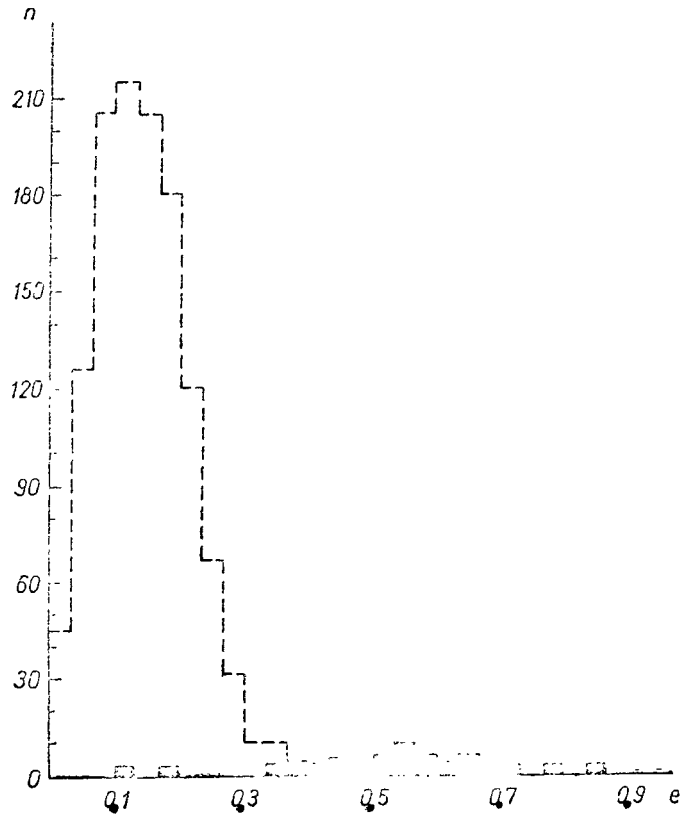

Fig. 9. Distribution of Eccentricities of Asteroids and Short-Period Comets (According to S.K. Vsekhsvyatskiy, 1933).

is much more concentrated around the plane of the ecliptic than is the system of short period comets. Considering this, we can obviously state that the short-period comets now observed are much younger formations, compared to the complex system of asteroids. /18

A comparison of the distributions of comets and asteroids, as well as an examination of individual orbits of a certain group, shows the close relationship between both systems. Apparently, this relationship is due to the characteristics of the genesis of both systems.

As a result of the calculations of Weiss and Schiaparelli 90 years ago, a relationship was found between comets and the famous Perseid and Leonid meteor showers; these showers were related to Comets 1862 III and 1866 I. (The Perseids were first observed in 1837 by Arago. The Leonids became famous after the celebrated meteor storm observed by A. Humboldt in 1779). It was later found that some other showers are also connected with comets; in Table 4

we have given the most certain instances of this relationship.

Considering this uncontested relationship between comets and meteor showers, F.A. Bredikhin constructed a theory on the formation of meteors (solid dust particles) from comets.

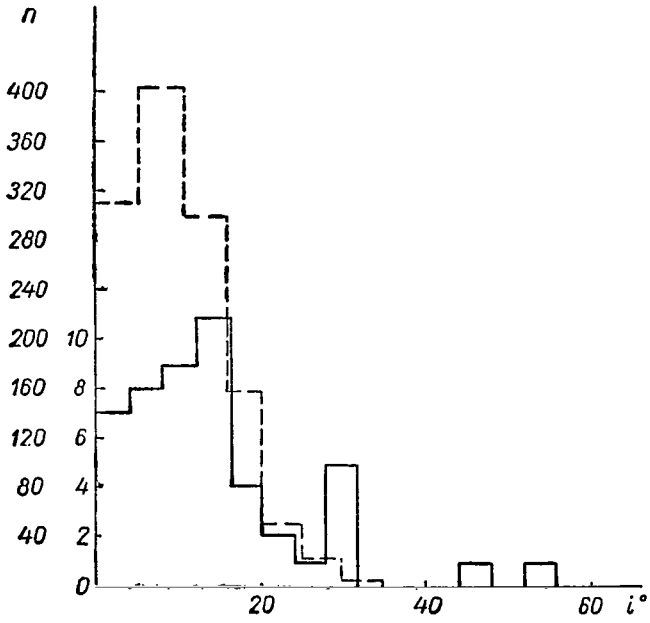

Fig. 10. Distribution of Angles of Inclination of Asteroids and Short-Period Comets (1933).

The bright Comet Arend-Roland (1957 III) was a graphic illustration of the validity of Bredikhin's theory; its remarkable anomalous tail, which was observed on April 23-28, 1957, was a mass of cosmic dust particles which had escaped from the nucleus of the comet.

There probably is a connection between meteor showers and Comets 1939 I, 1533, 1869 II, 1834, 1861 III, 1864 III, 1864 II, 1790 III, 1911 V, 1850 I, 1748 II, 1874 III, 1870 I, 1911 II, 1858 I, 1907 III, 1757 I and 1939 X; however, it is not as certain here as for the cases shown in Table 4.

We should also mention the results of an investigation of the orbits of meteorites, but with much less certainty, since our information is based on the last section of the path of meteorites in the Earth's atmosphere. /19

The most complete review of data on calculations of the orbits of meteorites is contained in the study by I.S. Astapovich [4], where the results of the first determinations of Pti, as well as those of Schiaparelli, Halley, H. Newton, Nissel, Pickering, and others were used.

I.S. Astapovich re-examined the results of the calculations from the positions of the idea of the interstellar origin of meteors, which was generally accepted in the 30's. The concept of sharply hyperbolic velocities of meteors was connected with systematic errors in visual observations, which led to the conclusion (mainly that of Hofmeister and Harvard astronomers) that meteors come from interstellar space.

TABLE 4

Meteor Shower	Date of Maximum	Comet	e	$i°$	P(years)
Lyrids	IV- 18-24	1861 I	0.983	80	415
Gamma-Aquarids	IV 28-V 5	Halley			
		1910 II	0.967	162	76
Bootids	VI 25-VII 2	Pons-	0.755-	11-22	5.6-6.2
		Winnecke	0.653		
		1819 III			120
Perseids	VIII 10-18	1862 III	0.960	114	
Draconids	X 10	Giacobini-	0.733	30	6.5
		Zinner			
		1900 III			
Orionids	X 18-22	Halley	0.967	162	76
Leonids	XI 15-17	1866 I	0.905	163	33
Andromedids	XI 13-28	Biela	0.725-	17-13	6.8-6.6
		1772	0.756		
Ursa-Minorids	XII 22	Tuttle	0.820	54-55	13.9-13.6
		1790 II			

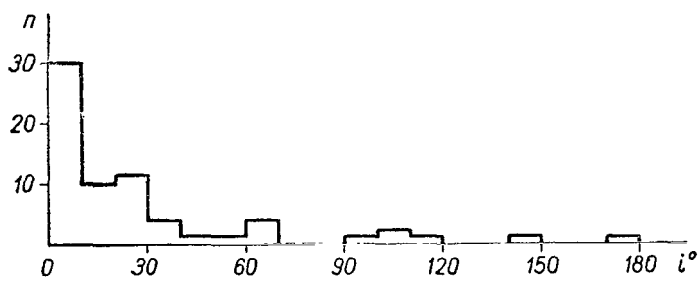

Fig. 11. Distribution of Inclinations i for 66 Meteorites (According to the Review of I. Astapovich).

Only at the beginning of the 40's was it shown that the primary heliocentric velocities of meteoric particles are elliptical in the overwhelming majority of cases, and that meteor showers cannot be streams of interstellar corpuscles.

I.S. Astapovich examined all the known radiants of meteor showers (66), calculating the orbits on the assumption that the velocities were elliptical, parabolic and hyperbolic. Despite some indefiniteness of the orbits, he found that the radiants of meteorites have a clear tendency to group around the equator or the ecliptic; more than half of all the orbits had perihelion distances near unity. /20

Of all the orbits considered, Astapovich found that elliptical eccentricities were more probable in 15 cases. From our point of view, the distribution of orbits by angles of inclination is most interesting (Fig. 11).

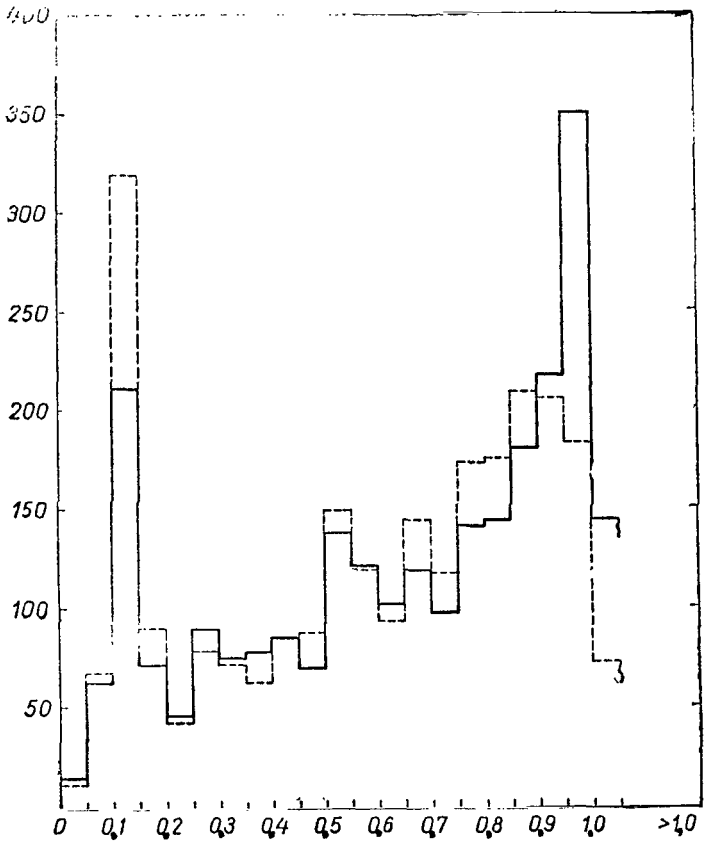

Fig. 12. Distribution of 2500 Photographed Meteors by q (McCrosky and Posen): Solid Line, Observed Numbers; Dotted Line, Weighted Values.

The distribution has a sharp maximum for i = 0 - 10°, and /21
corresponds well to the total distribution for short-period and periodic comets of the planet families. Since this element is determined more reliably, there is reason to assume that the data on the orbits of meteorites show a generic relation with the system of comets or comet-shaped asteroids.

In concluding this section, we will present the data on the most recent results of determinations of the orbits of individual meteors, as obtained from photographic and radar observations.

At the present, we have first-class series of photographic determinations of Whipple and Jacchia [5] and the less precise large series of McCrosky and Posen, as well as P.B. Babadzhanov, A.K. Sosnova, etc.

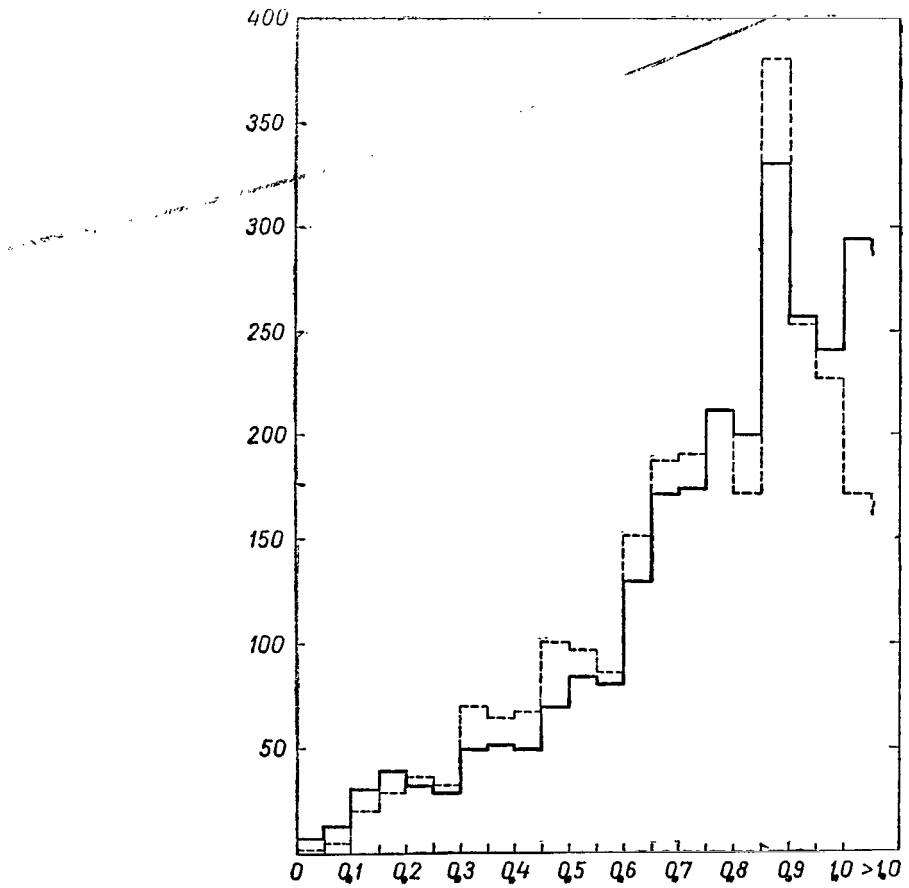

Fig. 13. Distribution of Meteors by e (McCrosky and Posen): Solid Line, Observed Figures; Dotted Line, Weighted Values.

Whipple and Jacchia summed up their results in the following way: of 251 orbits determined with particular accuracy (0.2% in velocity), there is not one case of hyperbolic motion; of 7 hyperbolas, corresponding to less accurate determinations, there is not one orbit where the long-period solution would not be within the limits of the error. Therefore, more than 99% of the particles, if not all, belong to the solar system. The nature of the orbits indicates that comets should be the source of 99% of these apparent meteors. /22

Particles of lunar origin cannot make up more than 1% of all the visible meteors observed.

The distributions of 2500 meteors by different orbital elements are given in the study of McCrosky and Posen. We will present some of these distributions (Fig. 12, 13, 14, 15).

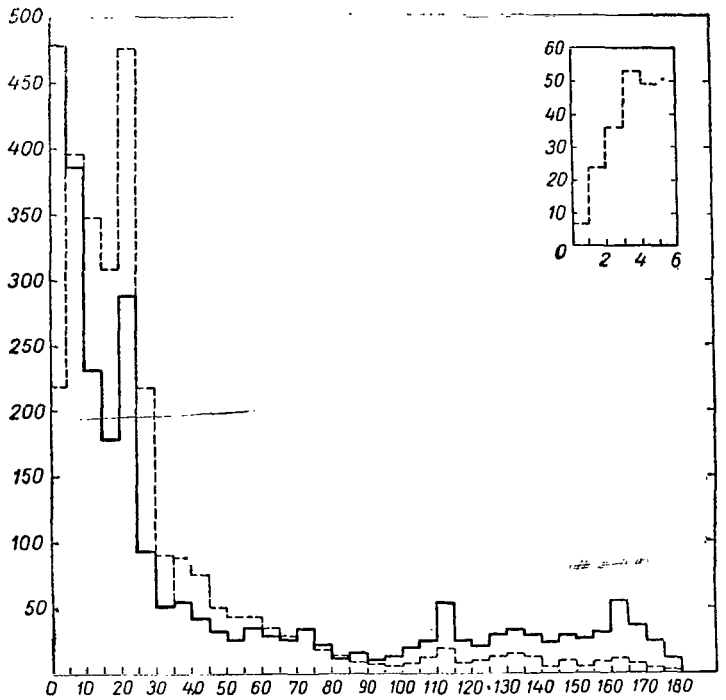

Fig. 14. Distribution of Meteors by i (McCrosky and Posen): Solid Line, Observed Figures; Dotted Line, Weighted Values (On the Right is the Distribution Near $i = 0°$).

Radar observations have been carried out at Jodrell Bank during the course of 12 periods with durations of 24 hours. Of 2400 orbits, 2000 with radiants north of the ecliptic have been analyzed. After making corrections for the velocity, as well as the declinations, the following results were obtained: there is a substantial number of orbits with $a < 1$ AU; meteors with long return periods ($a > 5$ AU) make up about 8% and have uniform distribution of inclination to $i = 90°$, but there are few orbits with retrograde motion. The intermediate orbits (a within the range of 2-5 AU) are characterized by a sharp concentration around the ecliptic ($i < 5°$) and constitute one fourth of the entire number of meteors with straight-line motion. The group of meteors with a in the range of 1.25-2 AU shows the same characteristics, but with less concentration around the ecliptic. In the smallest group with $a < 1.25$ AU, the orbits with great eccentricities show some concentration around the ecliptic, but the orbits with $e < 0.5$ have an i primarily in the neighborhood of 60°. Thus, regarding the nature of the distribution of elements of sporadic meteors, there is a clear connection with comets. /23

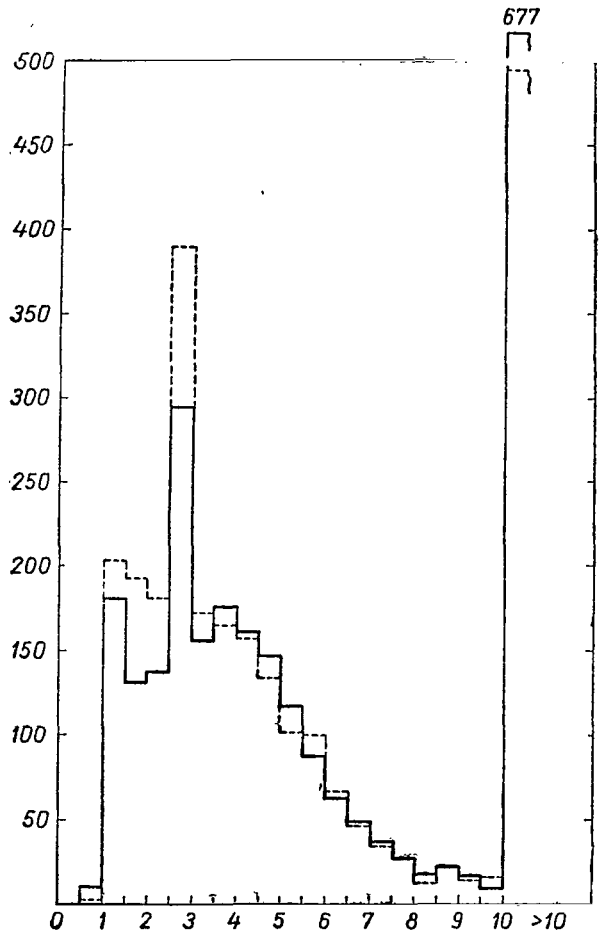

Fig. 15. Distribution of 2500 Photographed Meteors by Aphelion Distances (McCrosky and Posen); the Solid Line Designates the Observed Numbers, and the Dotted Line Represents Weighted Values.

The data of the investigation of V.L. Kashcheyev, V.N. Lebedinets and M.F. Lagutin, which were based on 12,500 orbits of radio meteors, allow us to conclude that numerous groups of meteoric particles, just as short-period comets, now appear in the central regions of the solar system [67]. /24

4. Comet Discoveries. Recent Comets

The astronomers of ancient China carefully recorded different unusual phenomena in the sky; the astronomical observations not only played an important role for counting days and regulating the calendar, but also had a more direct effect on the life of the country. The ancient Chinese considered the sky to be a great country consisting of regions and provinces, or constellations. The bright planets were imagined to be the rulers and directors of the provinces, and the stars were local organs of executive power. The comets were considered to be messengers sent to different provinces (constellations) to restore or maintain order there. The heavenly phenomena were viewed as the cause of what happened on the Earth, or as the effect of terrestrial events.

During the time when knowledge of the sky as the principal indicator of directions in travels, as well as the sign of the time of day or season of the year, was necessary for everyone, the bright comets were noticed by a large number of people. However, a systematic description of the phenomena in comets was a very rare case up to the 15th or 16th century. The observations of Toscanelli (Florence), who noted the position and characteristics of the appearance of Comets 1433, 1449, 1456, 1457 and 1472, were preserved, as were the particularly precise (for his time) observations of Comet 1472 by Regiomontanus. The latter made the first attempt at deter-

mining the distance to the comet. From 1531 to 1539, Apianus, the court astronomer of Charles V, observed five comets and noticed that their tails were always directed away from the Sun.

However, only after the observations of Tycho Brahe of the /25
extremely bright Comet 1577, as well as Comets 1580, 1582 and 1585, was the cosmic nature of comets shown; at this time, interest in discovering and observing comets began to increase. After the end of the 16th century, the number of astronomers in Europe and China increased continually, and systematic observations of comets were begun. Completely new prospects arose after the invention of the telescope and its application in astronomical observations by Galileo.

In the 17th century, particularly detailed observations of comets were carried out by Hevelius (Danzig, Gdynia), who discovered a number of comets and compiled the first cometographic study, "Prodromus cometicus" (1665). The "Teatrum cometicum" (1667-1681) of another Polish astronomer, Lubiniesky, which was published almost the same time, also played an important role.

At the end of the 17th century and the beginning of the 18th, several comets were discovered by LaGuerre, Cassini, Maraldi, Kirchol in Europe, and Fontenelle, Gian Priamo and Kegler in Peking.

In the second half of the 18th century, Messier, Méchain and Caroline Herschel were made famous by their discoveries; they can be called the first comet "hunters", working tirelessly on searches for nebulous moving bodies in the sky. Messier discovered his first comet in September 28, 1763; he discovered 17 comets in all. Among the comets Messier discovered, some were found to be short-period comets. The most remarkable bright comet (1770 I) was given the name of the Petersburg academician Lexell.

Méchain discovered his first comet in 1781, and he found 13 comets in 20 years. Comet 1786 I was named after the astronomer Encke, who studied its movement and finally showed that it is a short-period comet with return interval of 3.3 years.

Caroline Herschel, the sister of the famous William Herschel (who first discovered Uranus and founded stellar astronomy), discovered 7 comets from 1786 to 1797.

Of the comet researchers at the beginning of the 19th century, one who could be distinguished by his insatiability was Pons, who observed the sky first in southern France (Marseilles) and then in Italy. He discovered 33 comets from 1802 to 1827.

After systematic searches, it was found that several comets can be observed in one year, and the annual number of passages through the perihelion can even exceed 10, if the entire number of short-period comets returning to the Sun in 3-10 years is considered.

Therefore, astronomers agreed to give the comets special designations. The preliminary designations are given according to the year of the discovery, with the addition of a letter of the alphabet, depending on the number of the discovery. The comets are then arranged according to the time of the passage through the perihelion, and the final designation includes the year and numerical order of the passage through the perihelion (Roman numerals). For example, the first comet which Caroline Herschel discovered in 1791, which /26
was given the preliminary name 1791a, passed through perihelion on January 14, 1792. Its final designation became 1792 I. At the beginning of 1793, Gregory detected a comet which was given the preliminary designation 1793a; it passed through perihelion on December 1792, and was therefore called 1792 II.

At present, due to the fact that comets are discovered at different points of their orbit, or one before perihelion and the others after perihelion, it takes several years for the results of precise calculations to establish the final designations of comets in a given return to the Sun. The short-period comets, which return frequently to the Sun, are usually called by the name of the first discoverer or, in some cases, by the name of the man who calculated the motion of the comet in several appearances. For example, a significant number of comets bear the name of Pons (Pons-Winnecke, Pons-Brooks) or Tempel; such comets as Halley, Encke, Lexell and Crommelin are called by the name of the theoretician-mathematicians.

After Pons, W. Tempel became occupied with comet seeking. As many other comet discoverers, he began his activity in astronomy as a modest amateur. From 1858 to 1885, he discovered 19 comets, of which four (short-period) comets still bear his name.

Among the astronomy amateurs seeking comets, we should also mention Borelly and Coggia. One of the comets discovered by Coggia became the brilliant comet 1874 III, which grew a tail up to 60°. Winnecke (Berlin, Pulkovo, Strasbourg, Karlsruhe) discovered more than 20 comets, counting the precalculated returns of some short-period comets. Schweitzer (Moscow) discovered 5 comets; Bruns (Berlin, Leipzig) discovered 8 comets; d'Arrest (Leipzig) discovered 4 comets; Klinkerfuss (Göttingen) discovered 6 comets.

The names of two American astronomers have been written down in the history of cometary astronomy: L. Swift (Rochester) and W. Brooks (Geneva, New York). From 1862 to 1892, Swift discovered 13 comets. Brooks discovered 25 comets; his name belongs to three periodic comets.

A number of comets discovered by Tuttle (Cambridge), Brorsen (Kil), De Vico (Rome), Petersen (Altona), Donati (Florence), Becker (Nauen), Stephan (Marseilles), Borelly (Marseilles), Hartwig (Strasbourg), Tebbat (Australia), Denning (Bristol), and others.

The development of astronomical photography created new prospects for the discovery and study of comets, which is seen particularly clearly in the example of Barnard. E. Barnard (Nashville) began as an amateur astronomer, observing and seeking comets; from 1881, he discovered 17 new comets visually, and photographically from 1892, and he re-discovered several predicted returns of short-period comets.

After Barnard, Perrine continued the work of comet detections /27 at Lick Observatory; he discovered 8 comets. Giacobini, in Nice, discovered 12 new comets.

At the end of the 1890's and the first half of the 20th century, comets were studied mainly in a careful laboratory examination of photographic plates obtained in different programmed observations. Moreover, Wolf and Kopff (Heidelberg-Konigstuhl) carried out systematic comet seeking on such plates. Wolf found 2 comets, and Kopff found 5, of which 3 were new. The most remarkable comets of this period, Daniel 1907 IV and Morehouse 1908 III, were discovered and investigated with the aid of photography. The thirtieth appearance of Halley's Comet mentioned in history was also detected in 1909 (by Wolf) on photographs. A number of new discoveries and returns of periodic comets was detected photographically by Schaumasse (Nice) and Borelly (Marseilles).

In 1911, the first comet to be discovered in Simeiz (southern station of Pulkovo Observatory) was found by S.I. Belyavskiy. G.N. Neujmin found 7 comets from 1913 to 1941, of which 4 were new, while he was working with the binary astrograph of Simeiz Observatory. A bright comet, distinguishable with binoculars or with the naked eye, was discovered by Zlatinskiy in 1914.

The discoveries from the 20's to the 40's were connected mainly with the names of the astronomers who used wide-angle astrographs for different photographic studies. They were Metcalf, Reinmuth, Reede, Skjellerup, Johnson, Hubble, and others.

Since the 1920's, systematic observations of weak comets and, in particular, of the returns of short-period comets, began to be conducted at Yerkes and Lick Observatories (USA) by Van Briesbruck and Jeffers, and then Baade; large instruments were used, so as to shift into the range of the weak objects of sixteenth-twentieth magnitude.[2] During the same period, a significant number of observations of weak southern comets was obtained by Bobone in Cordoba.

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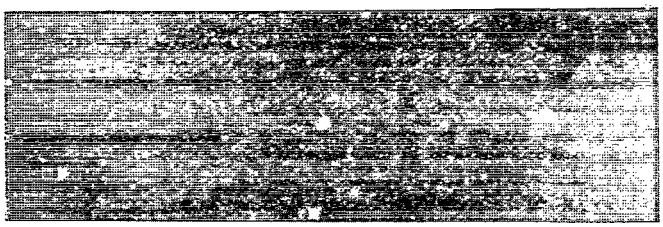
[2] Astronomers characterize the brightness of a star or some other heavenly body by the magnitudes (m); the brightest stars have magnitude of 0^m, and the brightness of stars which are 250 times weaker, hardly visible to the naked eye against the dark sky, is measured by the magnitude of 6^m. The magnitude of 16^m characterizes an object which is still 10,000 times weaker, and which can be observed only with large telescopes.

Particularly weak comets were photographed by Nicholson with the large telescopes of Mount Wilson Observatory.

During this period, Wirtanen discovered a number of weak comets on photographs from an 0.5-meter dual astrograph. Later, in the 40's and 50's, Wilson, Abel and Harrington began to discover new comets on the films of a 48-inch Schmidt telescope. In Abastumani, 4 comets were discovered by Tevzadze. Elizabeth Remer began to search for returning periodic comets and to observe weak comets in the 50's. /28

Together with the refinement of photographic observations, the binocular telescopes were found to be very effective. Recently, the Czechoslovakian astronomers Bechvar, Kresak, Pajdus-Akova, Mrkos and others have discovered 17 comets. Bakharev and Latyshev discovered 1 comet each.



October 12 October 18 November 3

Fig. 16. Outburst of Comet Schwassmann-Wachmann (I) in October, 1961 (The Positions of the Comet for October 12, 18 and November 3 are on the Continuation of the Lines Marked on the Side of this Composit Photograph).

Forty new comets were discovered from 1950 to 1959. In recent years, interesting bright comets have been discovered by the astronomer Honda (Japan), and the amateurs Peltier, Alcock (England), Ikeya and Seki (Japan) and Candy (England). We should also mention Abel, Arend, Burnham, Bester and Humason.

All this shows the very great potential of visual observations, in addition to photographs, when discoveries of comets emerging from behind the Sun or approaching it are very probable under the conditions of the evening or morning twilight sky.

Some of the comets which have been discovered during the last forty years are of exceptional interest.

Comet Schwassmann-Wachmann I (Fig. 16). The comet was discovered by the German astronomers Schwassmann and Wachmann (Bergedorf) on November 15, 1927. It appeared as a weak nebula of 13th magnitude with diameter of about 2′ (minutes of arc), or 15 times less than the diameter of the Moon. The comet moved very slowly in the sky, and nothing foreshadowed its remarkable characteristic features. However, two circumstances were noted after some time: it was found, firstof all, that the orbit of Comet Schwassmann-Wachmann is highly exceptional. The comet moves around the Sun in a near circle at a distance of more tham 6.0 AU, i.e. is further away than Jupiter. The return period of the comet is a little more

than 16 years. On the other hand, rather shortly after the discovery the comet showed outbursts of luminosity, while the brightness of the comet sometimes increased by a factor of tens and hundreds. The appearance of the comet changed at the same time of the luminosity flares: it appeared first as a diffuse nebulous disk, and then almost star-shaped. Careful observations showed that disruptions occur in the comet, and that the luminous matter is ejected, scattering in space after some time. /29

After the discovery, the comet passed through perihelion in 1941 and 1957. During the entire period of observations, it underwent tens of flare-ups, a list of which is given in Table 5. (The time interval when a particularly great increase in luminosity was noted is marked here, as well as the value for the "absolute magnitude"[3] H_{10} during this time).

TABLE 5

Observation Period	H_{10} (m)	Observation Period	H_{10} (m)
1927 XI 15—26	0,8	1949 I 23—II 2	0,8
1929 XII 2	1,5	1955 VII 12—16	1,9
1930 XI 23	2,4	1955 X 12—21	—2,6
1931 II 10	0,0	1956 IX 3	4,2 (D=25')
1933 I 20—24	—0,6	1957 VIII 31—IX 4	2,1
1933 III 21	0,9	1958 X 7—18	1,3
1934 IV 22	—0,5	1958 XII 2—4	1,3
1935 V 5	0,0	1958 XII 25—30	3,6
1937 V 15	1,5	1959 IX 1—10	0,2
1939 III 12—21	2,0	1959 X 5—10	—0,2
1941 VIII 29—12 IX	0,8	1959 XI	—0,4
1941 IX 24—27	1,8	1961 X 12—25	—1,0
1941 X 17—27	—1,5	1962 I 3—10	4
1941 IX 6—10	0,5	1963 II 25	3,5
1946 I 11	0,5	1963 X 25	4?
1946 I 25	—1,4	1964 X 5	2,1
1947 XI 12	—0,5	1964 III 15—17	0,3—1,3

The mean brightness curve during outbursts shows that there is a 25-30 day recurrence period in the outbursts, which clearly shows that the cause must be the solar corpuscular streams which are usually observed during solar eclipses as extended streamers of the solar corona. Thus, a distant flaring comet made it possible

[3] That value of the brightness of a comet which it would have when at a distance of one astronomical unit from the Sun and at the same distance from the Earth is called the absolute magnitude of the comet. The absolute magnitude characterizes the quantity of luminous material in the head of the comet and is found according to the formula $H_{10} = m - 5\log\Delta - 10\log r$, where Δ is the distance from the comet to the Earth; r is the distance from the comet to the Sun; m is the apparent magnitude of the comet, which is obtained from observations. The increase in absolute magnitude which is noted in many comets indicates that there is a secular decrease or depletion of comets.

to record the presence of solar corpuscular streams rotating together with the Sun.[4] /30

The results of a comparison between the moments of the flares of Comet Schwassmann-Wachmann I and magnetic storms on the Earth were also found to be of great interest. In many cases, it could be seen directly how a corpuscular stream which, bombarding the surface of cometary ice at a huge distance from the Sun, brought about an outburst, then approaching the Earth brought about perturbations in the geomagnetic field. This was an independent confirmation of the conclusion that solar corpuscular streams play an important role in interplanetary space.

The outbursts of Comet Schwassmann-Wachmann I were noted even in May-June of 1965. However, systematic decreases in the brightness of the comet were also remarked, which indicated that the frozen gases, or reserves of cometary ice, were being gradually depleted.

Comet Arend-Roland 1957 III. This bright comet was first discovered on November 6 and 8, 1956, on plates obtained by the astronomers Arend and Roland (Belgian Observatory at Uccle). It appeared as a weak, fuzzy nebula of 10^m, without traces of a tail, and was designated at first as Comet 1956h.

However, passing through perihelion on April 8, 1957, at a distance of about 50,000,000 km from the Sun, the comet increased in brightness to a large extent and, going into the northern sky around April 20-30, was seen as a bright facula with a tail greater than 30°. During this time, its head was equal in brightness to the brightest stars of the sky. The comet had an unusual appearance: in addition to a wide bright tail extending in a few streams from the head toward the Sun, a bright narrow emission directed toward the Sun extended from the nucleus of the comet. This anomalous tail also extended almost 15° and consisted of numerous meteoritic particles scattered in the plane of motion of the comet.

The photographs showed rapid changes in the tails of the comet. The masses of extremely rarefied cometary gas were carried away from the Sun at an ever increasing velocity, moving by the effect of huge repelling accelerations. The tail of the comet reached a length of 50 million km during the period of maximum development (IV/25-27, 1957). The radio-frequency emission of the comet and the source of radio waves moving in the tail were detected in the first half of April at radio-astronomical observatories in the USA and Belgium. However, these observations were not confirmed at other sites

[4] The Sun completes one revolution around its axis in roughly 25 days, revolving not as a solid body, but at a varying angular velocity at different heliographic latitudes.

Comet Mrkos 1957V (Fig. 17). The second bright comet of 1957 was given the name of Mrkos, a Czechoslovakian scientist who detected it visually towards the morning of August 2 and first informed the Central Bureau of Astronomical Communications at Copenhagen.[5] /31 Actually, the comet was first discovered in Japan on July 29 and then observed on July 31 by pilots flying high-altitude aircraft during the night. During the first period, the brightness of the head corresponded to that of first-magnitude stars, while the complex tail reached 10°.

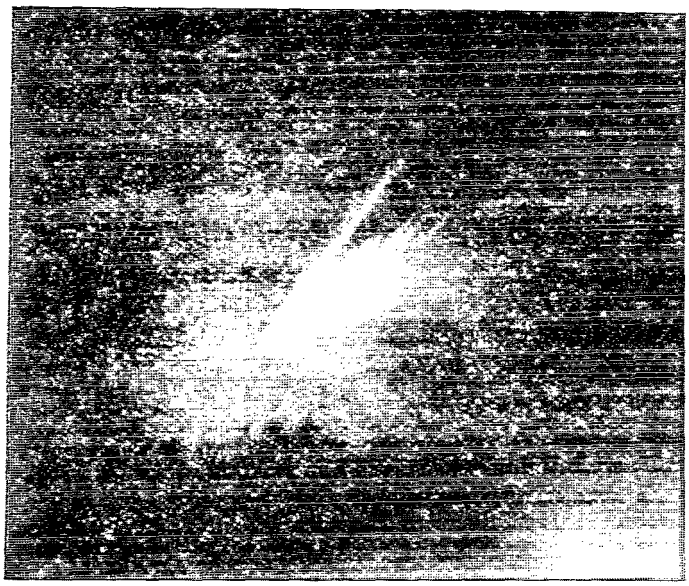


Fig. 17. Photograph of Comet Mrkos on August, 1957 (Obtained by McClure, California) with "Synchronous" Bands in a Type II Tail and a Straight Type I Tail.

The comet had a straight tail in which cloud masses, or bunches of cometary plasma, were carried at velocities exceeding 100 km/sec. Repelling accelerations which exceeded those due to the attraction of the Sun in magnitude by a factor of 500 were noted in the comet. A system of straight-line bands, or "synchrones", as Bredikhin called these bands at the end of the 19th century, was photographed over several days in August in the wide, bent type II tail. A study of the synchrones in Comet Mrkos showed, however, that they are not a cloud of solid particles ejected simultaneously from the nucleus, as considered in the mechanical theory of comets, but more /32 the manifestation of the regular magnetic field of the solar system. There should be a substantial number of charged particles, i.e., ionized molecules and possibly very small electrified dust particles, in type II tails.

[5] Since 1964, the International Bureau of Astronomical Communications has been situated in Cambridge (Massachusetts, USA).

Comet Burnham 1960 II. This comet was discovered on December 29-30, 1959 at Lowell Observatory, according to plates obtained with a 13-inch astrograph. It first appeared as a diffuse nebula of 11^m; however, when approaching the Sun (III/20/1960) it increased in brightness, and was observed in April in the circumpolar regions of the sky, situated conveniently for northern observatories. During this time, it appeared as an object of 4^m, i.e. not very bright. However, the photographs showed high activity in the comet; its thin type I tail, reaching 11° on a few nights, quickly altered its position relative to the extended radius vector (i.e., direction away from the cometary nucleus, opposit to the direction toward the Sun). The tail seemed to undergo the resistance of some medium, deflecting and inclining to one side and then the other. Particular activity was noted at the end of April and the beginning of May, when several flares occured in the head of the comet, as well as simultaneous rapid changes in the shape of the tail. It was found at Kiev that this could be the result of the characteristics of the movement of the comet around the Sun. The plasma tail of the comet, moving against the corpuscular streams revolving with the Sun, should have undergone much more powerful effects from these "magnetic bunches", since the relative velocity between the stream and the comet (due to the retrograde motion, oppositeto the foreward rotation of the Sun and its corona) increased by a factor of almost two, compared to analogous conditions for the comet with foreward motion.

Comet Wilson-Hubbard 1961 V. This bright comet with its long tail was discovered independently by Nikitin at Dushanbe and Hubbard at McDonald Observatory on July 23; it was named after the observers who made the first reports to the Central Bureau.

The comet passed through perihelion on July 17 at a distance of 5,000,000 km from the Sun. On the morning of July 23, a tail was seen over the northeast horizon, gradually rising with the Sun. The tip of the tail was a distance of almost 35° from the cometary nucleus; with such a long tail, the brightness of the head was insignificant; it appeared as a nebulous star of 3^m. A small anomalous tail directed toward the Sun was also noted in the comet; a week after the comet was discovered, it was seen at a distance of 3°. The investigations of the cometary spectrum showed that there was a large amount of dust in the tail.

The comet diminished rapidly. On August 6, it was hardly visible to the naked eye, although the tail could be seen up to 12° on the photograph. A week later, the comet diminished by a factor of 100, and was accessible to only the largest telescopes at the beginning of September. The last time the comet was observed on October 12, it was a million times weaker than when discovered. /33

During the period of maximum development, the straight-line tail of the comet was extended by 120,000,000 km; the matter of the cometary nucleus, undergoing the powerful effect of solar thermal

radiation, and particularly the effect of the rapid solar corpuscles (protons and electrons) transported from the surface of the Sun, was sprayed this enormous distance.

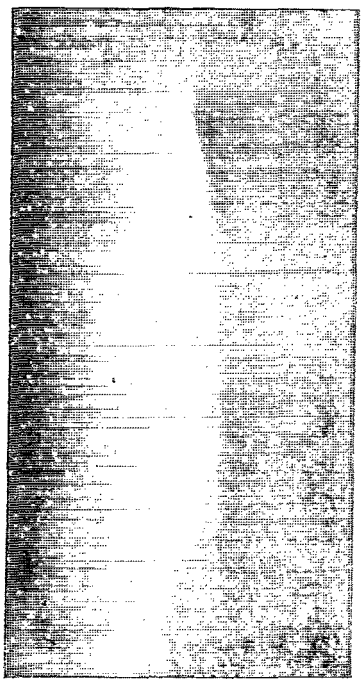


Fig. 18. Bright Comet Seki-Lines 1962 III (April 10, McClure, USA).

Comet Seki-Lines 1962 III (Fig. 18). This comet had a small perihelion distance (the comet passed by on April 1 at a distance of 4,000,000 km from the surface of the Sun), but it was discovered in February by two amateur astronomers, Seki in Japan and Lines in Arizona. At the time of its discovery, it was of 8^m, i.e., not visible to the naked eye. At the end of September, a very weak thin tail of almost 8° length could be seen on the photographs. In March, the tail exceeded 10° in length, while its tail reached 15° at the beginning of April, when the comet emerged in the northern sky after perihelion passage, and the head appeared as the brightest object in the sky. The cometary tail was of a very complex structure, with lengthwise "synchronous" bands, with streams of a rapidly-moving material and with a rather bright anomalous tail apparently consisting of dust particles.

Intensive emission of sodium vapor was noted in the spectrum of the comet, as well as the emision of neutral oxygen, corresponding to the "forbidden" line of aurorae (in the red spectral region), in addition to other ordinary cometary emissions.

On April 12-18, Pulkovo astronomers noticed a weak radio-frequency emission of the comet in their large radio-telescope, and they found a particularly active region which did not coincide with the comet's head, lasting several days. /34

The comet diminished rapidly and, after conjunction with the Sun at the end of October, E. Remer photographed an object of 20^m, i.e., tens of millions of times weaker than after the perihelion passage.

Comet Humason 1962 VIII. This was an exceptional comet in many respects. It was discovered at Mount Wilson Observatory by Humason on September 1, 1961. The preliminary designation of the comet was 1961e. It was a weak object of 14^m (several thousands of times weaker than the stars which are visible to the naked eye). As was found after its orbit was determined, it was at a distance of more than 5 astronomical units from the Sun during this time, or almost

the same distance as Jupiter. However, even in October rapid alterations in the shape of the comet were noted. Despite the vast distance, the cometary tail increased in length by almost 15 minutes of arc. In December of 1961, it flared up to 10^m; moreover, rapid changes were noted in the length and position of the tail, which sometimes disappeared completely and then re-appeared.

In May-July of 1962, when the comet came much closer to the Sun (it passed through perihelion at a distance of 2.1 AU on December 10, 1962), the photographs showed numerous rapid changes in the head, where outbursts completely changed the absolutely irregular structure of the comet. During this time, the luminosity of the comet corresponded to almost 6^m. In August, many observers in southern regions saw the comet visually as a diffuse object, with a tail. The tail could be seen as 2° long in binoculars on August 22.

On August 24, the comet was easily visible to the naked eye as 5.5^m, with a tail, but only as 9^m on August 20 (i.e., 20 times weaker) and without a tail. In September, high activity of the comet was again noted.

The spectrum of the comet also proved to be noteworthy; despite the great distance from the Sun, the ordinary emission of cyanogen and molecular carbon (CN and C_2) were either weak or absent, but ions of carbon monoxide and nitrogen (CO^+, N_2^+) were unusually intensive and observed over the entire head and tail. The rapid changes noted in the comet showed that powerful accelerations exceeding that of the solar attraction by thousands of times were acting here.

This comet was observed for several years after perihelion passage; first it flared up and then diminished. At the beginning of June in 1964, it converted from an object of almost the 18th magnitude to a bright nebula of 10^m; it was also observed in 1965 with the aid of large telescopes.

Comet Alcock 1963 III. The comet was discovered by the English /35
amateur astronomer Alcock on March 19, 1963 (the preliminary designation was 1963b). The comet was at first 8^m, with a small tail of 15'. Gradually increasing in brightness, it reached 6.8^m in May, but flared up by almost $2\text{-}2.5^m$ in several hours, and then increased by 0.7^m more. During this time, a disruption occurred in the nucleus of the comet, and the diameter of the cometary head increased almost twice, while the nucleus of the comet was divided into many parts. The tail reached 1° during the same time.

Calculations showed that the outburst occurred immediately when the comet, moving in a plane almost perpendicular to the plane of the ecliptic, descended from the northern to the southern regions, passing through the dense equatorial solar streams. This proved that the outbursts of the comets and the disruption processes occur

as a result of the effect of particles of corpuscular streams acting on the cometary ice.

In contrast to Comet Humason, a strong continuous spectrum was observed here; this indicated that there was a large quantity of meteoritic particles in the head. The C_3 and CN emissions were bright, while the ordinary C_2 bands were weaker.

In 1963, the comet moved to the southern sky, and was found around the southern pole at the end of February, 1964.

Comet Pereira 1963 V. This comet (1963e) was discovered on September 14 by Pereira in Cordoba (Argentina) as a bright luminary of 2^m, with a tail extending several degrees. In the three weeks before this, the comet passed through perihelion very close to the surface of the Sun, at total distance of about 20,000 km. The comet darted by at a velocity of more than 600 km/sec through the region of the inner corona, almost touching the chromosphere.

In this contest with the powerful force of the Sun, the comet apparently exhausted almost all the reserves of frozen gases, and it diminished very rapidly. Two days later, its brightness was evaluated as 6^m, while the tail was estimated at 10°. On September 21 and 22, a photograph of this comet with a faint tail of 18° was obtained in America. On October 31, the comet did not appear on the photographs, but the nucleus was found on November 9, with a tail of about 12′. Thus, substantial changes occurred in the comet; this indicated that the comet underwent vigorous alterations during the period of its flight near the Sun.

Comet Tomita-Gerber-Honda 1964c. This comet was noted for the exceptional activity in its tail. It was discovered independently on June 6 by Tomita (Japan), 1.5 hours later by Gerber (Argentina), and on June 9 by Honda (Japan). The comet was first a diffuse object of 6th magnitude, with a small tail. Approaching perihelion (VI/30/1964), it increased in brightness up to 4th magnitude. During this time, the thin tail of the comet reached 7°, while it increased to 30° at the beginning of July.

On July 3, a substantial deflection of the tail at a distance of more than 20° from the nucleus was found on the photograph. This activity of the tail was similar to the phenomena observed in Comet Burnham 1960 II. Doubtless this was connected with the characteristics of the motion of the comet. Comet Tomita-Gerber-Honda had retrograde motion, and during perihelion passage its tail should have collided with solar corpuscular streams at a very high relative velocity. Thus, the very appearance of the comet aided in conjecturing on the nature of the effects which bodies in interplanetary space undergo. /36

Comet Ikeya-Seki 1965f (Fig. 19). This comet was discovered on September 18, 1965, by the Japanese amateur astronomers Ikeya

and Seki. The comet moved toward the Sun, so that there were many unfounded reports on the comet colliding with the Sun, and on all types of effects which should accompany the collision. Actually, the comet passed through perihelion at a distance of 500,000 km from the solar surface (October 21 at 7:00 A.M. Moscow Time). During this time it was visible to the naked eye against the clear sky, in mountain regions.

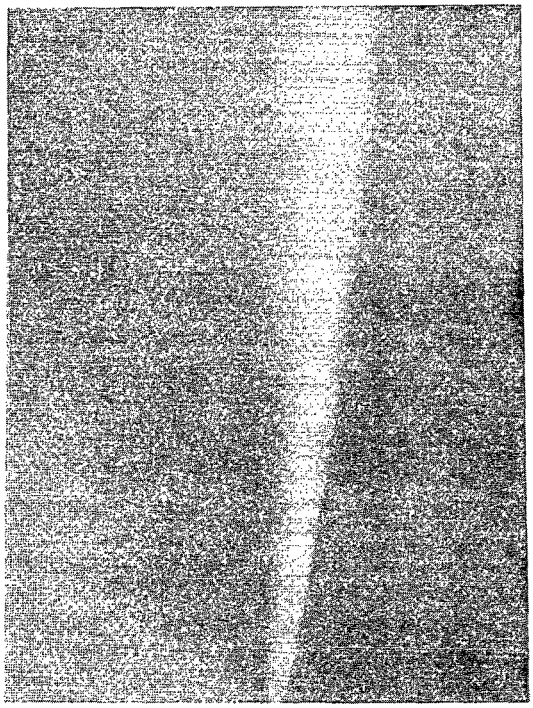


Fig. 19. Comet Ikeya-Seki 1965f, November 1, 11 Days After Perihelion Passage (According to McClure Photographs).

Astronomers of the Crimean /37
Astrophysical Observatory observed it during the day with the aid of special solar telescopes, where the quantity of scattered light was decreased.

In the equatorial and southern regions of the Earth, the conditions for investigating the comet during the approach toward the Sun were more advantageous. In Japan, the disruption of the cometary nucleus was observed shortly after perihelion passage.

Numerous lines of iron, nickel, cobalt, sodium and calcium were detected in the cometary spectrum obtained at different photographing observatories in Europe and America. This confirmed that meteorite masses were found in cometary nuclei, together with the ice.

Several days after the perihelion passage, the cometary tail could be seen in the morning sky in the form of a bright luminous band. The tail reached almost 40°. On October 27, the tail represented a twisted formation with many heterogeneities.

A regularity which had already been found was manifested in Comet Ikeya-Seki: the long tail of comets with retrograde motion undergoes rapid changes in shape and position as a result of an encounter with solar corpuscular streams at a greatly increased relative velocity.

Short-Period Comets Kerns-Kwi 1963 VIII, Su Chin Shan (I) 1965b and Su Chin Shan (II) 1965c. The short-period Comet 1963 VIII (preliminary designation, 1963d) was discovered on August 17, 1963, on a photograph obtained with the aid of a large Schmidt telescope

(Mount Palomar Observatory) by the astronomers Kerns and Kwi. It was first assumed that it was the short-period Comet Tempel-Swift, which had disappeared long ago, but the characteristics of the comet's motion were different. The comet was diffuse, with a small tail, and it corresponded to 12^m in total brightness. At the beginning of 1964, it was observed at many observatories, and the comet's orbit could be determined with sufficient reliability. It was found that the comet moves along an ellipse with a period of revolution of about 9 years, and with distance from the Sun at perihelion of 2.2 AU. Calculations showed that the comet should have made a near approach with Jupiter in October of 1961. Its absolute magnitude H_{10} was found to be equal to $8\text{-}6^m$, which showed that there was a substantial reserve of frozen gases in the cometary nucleus. The majority of astronomers considered that the near approach of the comet to Jupiter could imply the "capture" of this new comet by a giant planet, as a result of which the attractive force of Jupiter would convert the original orbit and lead the comet into the "visibility range", where it could be seen from the Earth. /38

At the very beginning of 1965, Chinese astronomers at the observatory of Purpurnaya Gora, near Nanking, discovered two faint comets. They were called Su Chin Shan (I) (discovered on January 1) and Su Chin Shan (II) (discovered on January 11). The brightness of these comets did not exceed 15^m.

Following the movement of new comets among the stars, the astronomers could determine their orbits after two months. Both comets were found to be short-period ones, with return period of 6-7 years; the perihelion distance for the first comet was 1.48 AU, and that for the second was 1.76. However, it was most amazing that, having calculated their return paths, the astronomers became convinced that both of these comets should have made near approaches to Jupiter in 1961, when they were at the aphelia of their orbits. The random encounter of a comet with Jupiter is a rather rare happening and can be estimated as a probability of 10^{-2} for the case of a short-period comet. The probability of almost simultaneous convergence of the planet with two comets is much less (it is evaluated as the product of the probabilities, i.e., 10^{-4}). However, we have seen that Comet Kerns-Kwi was near Jupiter at the very same time. The probability of this triple occurrence is found to be equal to 10^{-6}; thus, it was completely improbable that this could take place with comets which had existed for a long time, moving in the region of giant planets.

5. Phenomena in the Heads and Tails of Comets; Fundamentals of the Mechanical Theory of Comets

The characteristic features in the appearance of comets were noted in single descriptions by ancient observers. A bright nebulous head of a comet was accompanied by a wide, curving or thin, straight-lined tail. The records of ancient chronicles frequently compared comets to giant faculae whose flare extended over the sky.

The observations of Regiomontanus and Apianus showed that the tails of comets are almost always directed away from the Sun, which emphasized the decisive significance of solar actions on the formation of cometary tails.

Telescopic observations showed new characteristics in the structure of comets. A bright, sometimes star-shaped condensation, or the nucleus of the comet, from which streams and effusions forming the structure of the cometary head frequently extended, were found in the majority of cases inside the heads of the comets. The observations of bright comets in the 18th century and, particularly, in the 19th century not only confirmed that the head and tail are formed from luminous material flowing out of the nucleus, but they also pointed out the obvious validity of the idea expressed by Kepler and Newton, that the Sun has a repelling effect. /39

R. Struve, F. Bessel and other astronomers of the first half of the 19th century showed that there are shells on that side of the head of the comet which is turned toward the Sun. Several such luminous shells were observed in some comets.

Taking into account all the observations known at that time, I. Newton drew the conclusion "that the tail is none other than very fine vapor emitted by the head or nucleus of the comet as a result of its heating".[6] "The tails come from the heads of comets and are directed in the direction opposite to the Sun".[7] "...Kepler attributes their position in the direction opposite to the Sun to the effect of solar rays entraining the matter of the tails...That the most delicate evaporations in free space are inferior to the effect of the rays does not contradict common sense, despite the fact that in our regions crude matter does not take on substantial motion from the effect of the rays of the Sun..."[8]. Thus, even in the 17th century an examination of cometary phenomena showed that the Sun had a repelling effect.

In his classic memoir [6] treating the observations of Halley's Comet during its appearance in 1835, F. Bessel formulated the original positions of the mechanical theory of cometary forms in this way:

(1) The formation of the tails and head of a comet occurs by the effect of the repelling force of the Sun, just as the solar attraction, which is inversely proportional to the square of the distance from the Sun.

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[6] Newton, I.: Matematicheskiye nachala natural'noy filosofii (Philosophiae Naturalis Principia Mathematica), trans. A.N. Krylov, Book III, Petrograd, 1916, p. 294.

[7] Ibid, p. 295.

[8] Ibid, p. 299.

(2) The shape of the head of a comet is determined by the initial conditions, or the velocity and direction of the flows of gases and dust emerging from the nucleus, as well as the magnitude of the repelling force. The formation of paraboloid shells is the result of the "fountain theory" of the cometary head.

(3) The axes of the tails are located on the plane of the cometary orbit.

Bessel, and later Bredikhin, developed methods for reducing cometary observations on the plane of the cometary orbit, as well as the detailed theory of the motion of a particle in the head and tail by the action of an effective repelling acceleration. In the 20's and 30's, S.V. Orlov and his students refined this theory, as well as methods for projecting observations on the planet of the cometary orbit, and from the plane of the orbit to the sky [8].

Projection on the Plane of the Cometary Orbit. The geometry of the cometary forms is described, according to the mechanical theory, in a system of variable axes $O\xi$ and $O\eta$ occuring in the plane of the cometary orbit, with its center in the nucleus of the comet: /40 the axis $O\xi$ coincides with the radius vector of the cometary nucleus and is positive on the side away from the Sun (continued radius vector); the axis $O\eta$ is perpendicular to $O\xi$ and positive in the direction from which the comet moves. Thus, the position of the tail, which is usually inclined from the extended radius vector in the direction opposite to the movement of the comet, should be represented by positive values of the coordinates ξ and η. Obviously, the appearance of the comet in the sky will be determined not only by the actual processes in the head and tail, but also by the changes in position of the Earth (observer) relative to the plane of the cometary orbit. If the Earth is in the neighborhood of the plane of the cometary orbit and the structure of the comet is seen "from the side", an explanation of many characteristics of the phenomena in a comet is made very difficult. On the other hand, if the line of sight forms a small angle with the perpendicular to the plane of the orbit in the nucleus of the comet, the position of the tail in the orbit's plane is seen almost without distortion, so that the effect of the Sun on the cometary matter can be investigated.

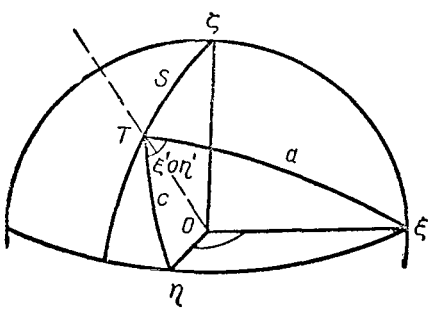

Fig. 20. Cometocentric Sphere.

We will examine one of the methods for projection; it is the simplest and is symmetric with respect to the coordinates ξ and η [64].

Let the point T on the cometocentric sphere (center in the nucleus of the comet) mark the direction to the Earth (Fig. 20); at points ξ and η on the equator (corresponding to the intersection of the sphere with the plane of the cometary orbit), the axes $O\xi$ and $O\eta$ intersect with the sphere. At the point ζ (pole), the perpendicular to the orbit in the cometary nucleus intersects with the sphere. It is obvious that $\zeta\xi = \zeta\eta = \xi\eta = \frac{\pi}{2}$, and all the angles in the spherical triangle $\zeta\xi\eta$ are also equal to $\frac{\pi}{2}$.

It is easy to see that the angle at T in the spherical triangle $\xi T\eta$ represents the projection of the coordinate angle $\xi O\eta$ in the plane of the cometary orbit onto the sky. We will call this transformed angle $\xi' O\eta'$. The angle $\xi' O\eta'$ can be found if the coordinates of all three vertices are known.

The position of the Earth on the cometocentric sphere can be obtained on the basis of the geocentric ecliptical coordinates of the cometary nucleus at the moment of observation λ and β. Then

$$\begin{aligned} \sin S \sin l_{\oplus} &= -\sin\beta \sin i - \cos\beta \cos i \sin(\lambda - \Omega), \\ \sin S \cos l_{\oplus} &= \cos\beta \cos(\lambda - \Omega), \\ \cos S &= -\sin\beta \cos i + \cos\beta \sin i \sin(\lambda - \Omega), \end{aligned} \qquad (1)$$

/41

where S is the so-called Bessel angle in the nucleus of the comet, between the perpendicular to the orbit of the comet and the line of sight (direction toward the Earth); it is obvious that the cometocentric latitude of the Earth $b_{\oplus} = S - 90°$. The coordinates of the point ξ are equal to the following: $b_{\xi} = 0$, $l_{\xi} = v + \omega = u$, i.e., the argument of the latitude of the cometary nucleus, since the direction of the continued radius vector ($O\xi$) on the cometocentric sphere, reading in the planet of the cometary orbit from the direction to the ascending node, also corresponds to this angle. Then, $b_{\eta} = 0$ and $l_{\eta} = v + \omega - 90°$. Knowing the coordinates of the vertices in the triangle $\xi T\eta$ and one of the sides ($\xi\eta = 90°$), we will determine the arcs of $T\xi = a$ and $T\eta = c$.

$$\begin{aligned} \cos a &= \cos(l_{\oplus} - u)\cos b_{\oplus}, \\ \sin a \sin A_{\xi} &= \sin(l_{\oplus} - u), \\ \sin a \cos A_{\xi} &= -\cos(l_{\oplus} - u)\sin b_{\oplus}. \end{aligned} \qquad (2)$$

Since $\sin a > 0$, then A_{ξ} is completely defined.

In a similar way,

$$\begin{aligned} \cos c &= -\sin(l_{\oplus} - u)\cos b_{\oplus}, \\ \sin c \sin A_{\eta} &= \cos(l_{\oplus} - u), \\ \sin c \cos A_{\eta} &= \sin(l_{\oplus} - u)\sin b_{\oplus}; \end{aligned} \qquad (3)$$

a and c are the angles which the line of sight forms with the coordinate axes $O\xi$ and $O\eta$ in the nucleus of the comet; the angle $a = 180°-k$, where k is the phase angle (angle in the nucleus of the comet between the directions to the Sun and the Earth). Moreover, it is obvious that $A\xi - A_\eta = \xi' O\eta'$, if $b_\oplus > 0$ and $A_\eta - A\xi = \xi' O\eta'$ $b < 0$.

The following formula can be used to check the calculations:

$$\cos \xi' O\eta' = -\cot a \cot c. \tag{4}$$

Thus, by using relatively simple calculations we can have a complete representation of the conditions for projection of cometary phenomena in the sky.

The position of the continued radius vector on the map or photograph, i.e., the position of the $O\xi'$ axis (it is represented by the arc of the major circle passing through the position of the Sun and the comet at the moment of observation) can be found according to the following formula:

$$\sin(\alpha_0 - \alpha_\odot)\tan\delta_\odot - \sin(\alpha_0 - \alpha_\odot)\tan\delta + \sin(\alpha - \alpha_\odot)\tan\delta_0. \tag{5}$$

Given α, we can find δ of the point of the $O\xi'$ axis, if α_0, δ_0 /42 (coordinates of the nucleus) are known at the moment of the observation; $\alpha_\odot$, $\delta_\odot$ are the coordinates of the Sun.

The points of the $O\eta'$ axis can be determined from the following formula:

$$\tan\delta = \frac{\sin(\alpha - \alpha_0)}{\tan p_\eta \cos\delta_0} + \tan\delta_0 \cos(\alpha - \alpha_0); \tag{6}$$

where $p_\eta = p_\xi \pm \xi' O\eta'$ (the sign depends on the direction of the axis $O\eta'$); and p_ξ is the position angle of the continued radius vector.

Knowing the angle $\xi' O\eta'$ and the values of a and c for the moment of observation, we can easily obtain the cometocentric coordinates ξ and η on the plane of the cometary orbit for any detail of the comet (axis, tip of the tail, single bunches or rays) on the photograph.

We will measure the position of details on the plate by the distance from the nucleus s and the angle $\phi = p - p_0$ ($p - p_0$ is the difference in position angles of the measured point and the continued radius vector). Then on Figure 21, where the continued radius vector of $O\xi'$ and $O\eta'$ is depicted on the geocentric sphere at an angle of $\xi' O\eta'$, we have $\angle \xi' OS = \phi$ and $OS = s$ (S is the measured point of

the tail.

Let us put the point N on $O\eta'$ on the condition that $ON = 180° - c$, and the point M on $O\xi'$, for $OM = 180° - a$. It is obvious from the projection conditions that, if the arc of the major circle is drawn through N and S, it will intersect $O\xi'$ at the point L, while $OL = \xi'$, i.e., the angle at which the true coordinate ξ of the point S in the plane of the cometary orbit is seen from the Earth. It is also found in this way that $OP = \eta'$. Moreover, $\sphericalangle SON = \xi' O\eta' - \phi$.

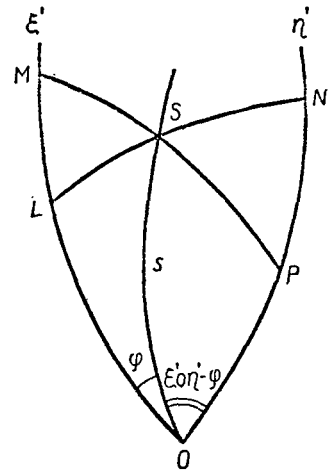

Fig. 21. Projections of Cometocentric Coordinates on the Geocentric Sphere.

The angle for N is then determined from the triangle SON thus:

$$\tan N = \frac{\tan s \sin(\xi' O\eta' - \varphi)}{\sin c + \tan s \cos c \cos(\xi' O\eta' - \varphi)}, \tag{7}$$

while, from the triangle LON

$$\tan \xi' = \frac{\sin c \tan N}{\sin \xi' O\eta' - \tan N \cos \xi' O\eta'} = \frac{\tan c \tan s \sin(\xi' O\eta' - \varphi)}{\sin \xi' O\eta' \tan c + \tan s \sin \varphi} \tag{8}$$

Similarly, we find the following from the triangles MOS and MOP: /4

$$\tan \eta' = \frac{\tan a \tan s \sin \varphi}{\sin \xi' O\eta' \tan a + \tan s \sin(\xi' O\eta' - \varphi)}. \tag{9}$$

After this,

$$\xi = \Delta \frac{\sin \xi'}{\sin(a + \xi')} \text{ and } \eta = \Delta \frac{\sin \eta'}{\sin(c + \eta')}. \tag{10}$$

Elements of the Mechanical Theory. The positions of details in the tail or head on the plane of the cometary orbit which we have just obtained can be compared to the theoretical syndynames, which can be represented by the following approximate expression:

$$\eta = g \sin G \left[\frac{r\sqrt{2\xi}}{\sqrt{1+\mu}} - \frac{4er \sin v}{3(1+\mu)\sqrt{p}} \xi \right] + \frac{2\sqrt{2p}}{3r\sqrt{1+\mu}} \xi^{\frac{3}{2}}. \tag{11}$$

Here g is the initial velocity of the particle ejected at an angle of G to the radius vector of the cometary nucleus; $1 + \mu$ is the effective acceleration, which is expressed in units of the solar attraction, at a distance of r; e, p and v are the eccentricity,

the parameter of the orbit, and the real anomaly of the comet, respectively. The unit time is $1/k = \frac{365.25}{2\pi} = 58.132$ days, while the unit length is one astronomical unit ($1.496 \cdot 10^{13}$ cm).

Comparing the position of the tail axis with the theoretical syndynames, we can estimate the value of the average repelling force forming the tail. Finding the envelope of all the particles leaving the nucleus at a certain moment $t - T$ and moving by the effect of the force of $1 + \mu$, we can obtain the equation for the parabolic envelope of the fountain theory:

$$\eta^2 = \frac{2g^2r^2}{1+\mu}\xi + \frac{g^4r^4}{(1+\mu)^2}. \qquad (12)$$

The apex of the parabola is the following distance away from the nucleus of the comet:

$$\varepsilon = \frac{g^2r^2}{2(1+\mu)}. \qquad (13)$$

The use of such approximate formulas allowed Bredikhin to find the existence of four types of cometary tails, which was later tested by calculations according to precise formulas for hyperbolic motion.

According to F.A. Bredikhin, comets can have the following tails:

Type I: straight-line, slightly curving, usually thin, formed by forces of $1 + \mu = 10\text{-}20$, for initial velocities of $g = 0.2\text{-}0.1$ (i.e., about 6-3 km/sec);

Type II: broad, curved, largely diverging from the extended radius vector ($1 + \mu \approx 1\text{-}4$, $g \approx 0.06\text{-}0.01$; i.e., $\approx 2\text{-}0.3$ km/sec);

Type III: usually short, largely diverging from the extended radius vector, formed by forces of $1 + \mu \approx 0.1\text{-}0.5$; /44

Type IV: often located in the region of negative ξ and η, i.e., directed toward the Sun (the so-called anomalous tails). Bredikhin considered that a repelling force does not act on particles of such tails, and that they are formed by heavy particles moving at substantial velocities from the nucleus of the comet.

The conclusion that the anomalous tails have a dust nature have been confirmed repeatedly, particularly with the phenomena in the bright Comets Arend-Roland 1957 III and Seki-Lines 1962c.

In a study by A.A. Demenko on the types of cometary tails[9], there are data on 167 comets, of which the tails of 112 comets were investigated by the author. Of the 800 recorded appearances of comets, 65% had one tail, 29% had two tails, and 6% had three or more tails.

Type I tails are observed most often; the anomalous tails have been found in more than 25 comets. The maximum recorded length of type I tails did not exceed 0.5 AU; type II tails reached 1 and even 2 AU in individual cases.

Bredikhin suggested that Types I, II and III tails are formed by gaseous particles of different kinds. Some contemporary astronomers consider that types II and III tails are made of dust, a conclusion based mainly on spectroscopic observations.

A study of the so-called synchronous formations in type II tails leads to conclusions that these tails have a gaseous nature [7].

The approximate synchrone equation can be obtained by taking the temporal values out of the famous expressions for the cometocentric coordinates:

$$\eta = \frac{2p\tau}{3r^2\sqrt{p} + 4e\tau r\sin v}\xi + \tau g\sin G - g\cos G\frac{\sqrt{p}}{r^2}\tau^2. \qquad (14)$$

For small values of τ (time interval after ejection of the particles), the synchrone is close to a straight line passing through the nucleus [10].

Bredikhin mistook the characteristic bands observed in the bright Comet 1844 and Comet Donati 1858 VI for synchrones, and he attributed details of Comets 1865 I, 1882 I and 1882 II to synchrones. K.D. Pokrovskiy studied distinct "synchronous" bands which were photographed in Comet 1910 I.

The detailed investigation of the system of bands observed in Comet Mrkos 1957 IV which S.K. Vsekhsvyatskiy conducted showed that these bands could not be synchrones (i.e., simultaneously ejected clouds of particles), considering their position and many characteristic aspects, but that they were apparently the reflection of electromagnetic processes in the plasma of the cometary tail. The existence of plasma tails was made obvious even before in a study of the spectra of type I tails. The "synchronous" nature of the tails indicated that type II tails are also gaseous, with a substantial number of charged particles, that the structure of the tails /45

[9] Demenko, A.A.: Tipy kometnykh khvostov. Sb. Fizika Luny i planet (Types of Cometary Tails. In the Collection: Physics of the Moon and Planets). Kiev, "Naukova Dumka", 1964.

is determined mainly by the electromagnetic forces, and that the arguments of the mechanical theory are insufficient. Nevertheless, many methods of the mechanical theory remain of value in studies of the processes in comets. The role of comets as natural and unique indicators of the conditions in interplanetary space is becoming more and more obvious.

A determination of the values of the repelling accelerations is of great interest and can be accomplished on the basis of an investigation of the movement of single details or clouds in the tails of comets. One of the first such determinations was conducted by Bredikhin, for Comet 1893 II, according to the observations of Hesse. Using the expression for the velocity of the cloud for the value of r_1 at the moment of emission, i.e.,

$$H^2 = \frac{2}{r_1} + \frac{2\mu (R + r_1)}{Rr_1}, \qquad (15)$$

Bredikhin found that $\mu = 246$ and $1 + \mu = 247$. This value is almost one order of magnitude greater than that obtained according to data on the curvature of tails; later, after Hesse corrected the error, the repulling force was found to be within therange of 35-40. Studying the motion of details on photographs of Comet 1903 IV, Bredikhin found $1 + \mu$ in the limits of 67-77. More precise methods of calculating the orbits of clouds formations, which were used by A. Egerman, A. Kopff, A.Ya. Orlov, S.V. Orlov, K.D. Pokrovskiy, N. Bobrovnikoff and others, gave very different results for the repulsive force (from 35 to 71 for Comet 1892 I; 90 for Comet 1903 IV; from 62 to 162 for Comet 1908 III; about 70-90 for Comet 1910 II; up to 1940 for Comet 1943 I; to 1000-2000 for Comet 1957 III) [8].

N. Bobrovnikoff found the existence of abrupt changes in the movement of cloud formations during his thorough investigation of the processes in Halley's Comet; this does not allow us to assume that the repelling forces are constant.

6. Brightness and Absolute Magnitudes of Comets

An investigation of the brightness of comets allows us to determine the nature of their emission, to evaluate the quantity of gaseous or dust-like material in the head of the comet, and to explain the laws for the change in their brightness and the nature of the phenomena in cometary nuclei. Considering the secular variations in brightness of periodic comets, their disintegration rate and duration in the form of cometary objects can be estimated. The /46
possibility of using comets as indicators of solar activity and the conditions in interplanetary space has become clear during the last few years.

These prospects in the photometry of comets were found as a result of investigations by Soviet astronomers during the last 40

years. They were a continuation of many years of studies by the Viennese astronomer I. Holetchek, concerning a collection of photometric estimates of comets and observations of their brightness.

However, Kepler, Hevelius, Cizat, Flemstid, Messier, Herschel, Struve, Winnecke, Schmidt and others had estimated the brightnesses, and Newton and Olbers noted the value of cometary photometry long before then.

Laws for the Change in Luminosity of Comets. In 1916, S.V. Orlov found that the exponent n in the approximate law for the change in brightness of comets $I = \frac{I_0}{r^n \Delta^2}$ is much greater than 2 and closer to 4 for several comets.

Using an analysis of hundreds of photometric curves, S.K. Vsekhsvyatskiy established the average law for the change in integral brightness of comets, which corresponded to $n = 4$.

The absolute magnitudes of comets were determined for practically all the catalogued cometary appearances (860) from a set of equations of the type

$$H_{10} = m - 10 \log r - 5 \log \Delta, \qquad (16)$$

where m is the apparent magnitude of the comet.

For appearances with sufficient luminosity estimates and precise photometric observations referring to a substantial change in r, the photometric parameters H_y and y were found, in addition, from equations of the following type:

$$H_y = m - y \log r - 5 \log \Delta. \qquad (17)$$

The absolute magnitudes and photometric parameters which Vsekhsvyatskiy determined, and which V.P. Konopleva and T.V. Vodop'yanova found for some recent comets, are published in the book "Fizicheskiye kharakteristiki komet" ("The Physical Characteristics of Comets") [9].

The numerous estimates of Holetchek, which are closely connected with the system of Bonner-Durchmusterung, as well as the estimates of Vsekhsvyatskiy, continuing Holetchek's system, are the basis of the system of absolute magnitudes. This comment must be made with regard to the statements on the overestimation of luminosity for comets of the past; an examination of the problem indicates that the opposite is more probable.

Absolute magnitudes of comets. The absolute magnitudes of comets vary within a very wide range from $H_{10} = -3^m-2^m$ (Comets 1829, 1577; Comet Schwassmann-Wachmann reaches the same values during the flare period) to $H_{10} = 15.2^m-15.8^m$ (1961 IV, 1962 I, 1961 II, and the recent appearances of the depleting short-period Comets Wirtanen, Perrine-Mrkos, and Harrington-Abel). /47

The distribution of absolute magnitudes of near parabolic comets (P > 1000 years, parabolas and hyperbolas) is represented in Figure 22.

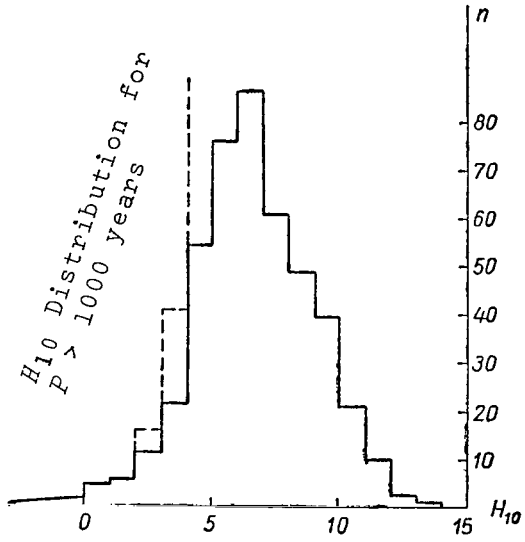

Fig. 22. Distribution of Absolute Magnitudes of Near Parabolic Comets; the Dotted Line shows the Reduced Distribution.

The curve for the distribution of absolute magnitudes reflects the conditions of observational selection in the discovery of new comets to a large extent. In this regard, it is interesting to see how the average absolute magnitudes (H_{10}) depend on the time of the discovery (see Table 6).

The effect of the beginning of telescopic observations and the systematic increase in effectiveness of sky surveying is clearly noticeable. Nevertheless, the gain in H_{10} does not exceed 3-4^m in the 350-year period of telescopic astronomy. This can be explained by the fact that, together with the discovery of absolutely faint

TABLE 6

Period	To 1500	1500—1549	1550—1599	1600—1649	1650—1699	1700—1749	1750—1799	1800—1849	1850—1899	1900—1949	1950—1966
No. of Comets	21	4	9	2	15	17	35	59	122	118	48
Absolute Magnitude	4.1	2.7	4.2	5.3	5.0	4.3	6.1	6.1	6.8	7.4	7.5—8

comets with perihelion distance in the neighborhood of q = 1 AU, the number of discoveries of distant comets with high q also increased. The range of values for H_{10} is expanded, while the center of the distributions shifts away from the Sun relatively slightly. Actually, having compared the new discoveries in the first half of the 17th, 18th, 19th and 20th centuries, we can find limit values of H_{10} as 6.0, 7.3, 9.0, and 11.5, respectively. This increase also characterizes the actual effectiveness of modern sky surveying. /48

The problems of considering the observational selection, or the "visibility conditions", were examined by Holetchek and, later, N.D. Moiseyev, Bourgeois, Cox, Dombrovskiy and other astronomers. The order of the corrections for the probability of a discovery can also be obtained from the following concepts. Considering only the apparent magnitude as a function of the heliocentric distance of the comet on the average, we can estimate the probability of a discovery with respect to the time the comet exists inside spheres of radii r_2 and r_1, on the condition that the apparent magnitude is less than some limit value, depending on the observational media:

$$m_{\lim} = H_1 + 10 \log r_1,$$
$$m_{\lim} = H_2 + 10 \log r_2.$$

Therefore, we can write $r_2 = r_1 \cdot 10^{0.1(H_1 - H_2)}$. The relative probability of a discovery, which depends, according to the condition, on the time in which the comet remains inside spheres of r_2 and r_1, is then equal to the following:

$$W = \frac{\sqrt{r_2 - q}\,(r_2 + 2q)}{\sqrt{r_1 - q}\,(r_1 + 2q)}. \qquad (18)$$

Taking $r_1 = 3.0$ and $q = 0.3$ (which correspond to average values), and considering that all comets with $H < 2^m$ will be discovered, we can obtain the "corrected" distributions, which are depicted in Figure 22 by the broken line.

The average values do not show any systematic variation as a function of inclination. However, there is a decrease in the number of comets in the range of i = 110-120°, which is also in correspondence with the increase in average luminosity of comets by almost precisely 1^m. Moreover, let us note that comets with retrograde motion (i = 160-180°) are almost 1 absolute magnitude fainter, on the average, than comets with foreward motion (for i = 160-180°, $H_{10} = 7.2^m$; for i = 0-20°, $H_{10} = 6.3^m$).

Quantity of Luminous Molecules and Dust in the Heads of Comets. The absolute magnitude characterizes the quantity of luminous matter in the head of a comet. Considering the mechanism of resonance excitation of cometary molecules shown both in the calculations of K. Wurm and in the study of the profiles of the molecular bands (P. Swings, Kepler, etc.), the following relationship can be written for the amount of energy emitted by the gaseous component per unit time: /49

$$E = N\omega B_{1\to 2}\rho_{\nu_{\odot}} h\nu,$$

where ν is the average frequency of the molecular bands under investigation, N is the total number of molecules in the head in the

ground electron state; $w = \frac{1}{4}\frac{R^2}{r^2}$ is the dilution factor; $\rho_{\nu,s}$ is the density of the solar emission energy at frequency of ν; $B_{1\to 2}$ is the Einstein coefficient of the probability of transition from the ground electron level to the nearest excited level.

Assuming that all this exciting energy is re-emitted spontaneously, let us calculate the apparent visual magnitude of a comet which is determined by this emission in the molecular band.

If κ_λ is the coefficient of the sensitivity of the eye for the band under investigation, then the illumination from the comet is equal to the following:

$$\frac{\kappa_\lambda N w B_{1\to 2}\rho_{\nu,s} h\nu}{M \cdot 4\pi\Delta^2}\ (\text{phot}),$$

where M is the mechanical light equivalent ($M = 1.61\cdot 10^4\ \frac{\text{erg}}{\text{sec.lux}}$) and Δ is the distance from the comet to the Earth in centimeters.

Since the illumination from a star of 0^m is equal to $2\cdot 10^{-10}$ phot or $2\cdot 10^{-16}$ lux, the stellar magnitude of the comet is the following:

$$m = -2{,}5\log\left[\frac{\kappa_\lambda N w}{8M\pi\Delta^2} B_{1\to 2}\rho_{\nu,s} h\nu \cdot 10^{10}\right]. \qquad (19)$$

$B_{1\to 2} = \frac{\pi f_{1\to 2} e^2}{\mu h\nu}$, where $f_{1\to 2}$ is the oscillator strength for the band; For the maximum sensitivity (5500 Å), we can assume that κ_λ is equal to 1. Considering r and Δ as also equal to 1, we can find the following for the absolute magnitude of the comet:

$$H_{10} = -2{,}5\log\left[\frac{N f_{1\to 2} e^2 \rho_{\nu,s}\cdot 10^{10}}{8\pi \cdot 4 \cdot 214^2 \cdot \mu}\right]. \qquad (20)$$

For C_2, whose band is characterized by the emission of the comet in the visual region, $f = 0.02$. Expressing $\rho_{\nu,s}$ in terms of a Planck function and considering the temperature of the solar photosphere to be $T = 6000°K$, we find that

$$H_{10} = 2{,}5\log 10^{35} - 2{,}5\log N$$

or

$$N = 10^{35-0{,}4H_{10}}.$$

This estimate was made on the assumption that the entire visual luminosity of the comet was due to the emission of the Swann C_2 bands. Actually, we must consider the often significant contribution of the continuous spectrum of the comet, and the presence of numerous other gaseous components in the head. According to the calculations of K. Wurm [10], the average density of C_2 molecules in the heads of bright comets can be equal to 10^2 cm^{-3}. This yields a density on the order of 10^7-10^8 cm^{-3} near the nucleus, and $10^{5.5}$ cm^{-3} at a distance of 10,000 km. /50

Wurm estimated the density of CO^+ molecules in these tails as 300 cm^{-3} (in this case, f for CO^+ was taken as equal to 0.002) on the basis of photometry of type I tails.

According to B.A. Vorontsov-Vel'yaminov, the quantity of CN molecules is on the same order as the C_2, while there are 30 times fewer C_3 molecules.

The density of the C_2 in Comet 1955 III was equal to $3 \cdot 10^3$ cm^{-3} near the nucleus and 70 cm^{-3} at a distance of 50,000 km from the center, according to Husiot. For the famous short-period Comet 1959 VIII (Giacobini-Zinner), Mianes, Grudzinskaya and Stavikovskiy obtained a density on the same order (10-10^2 cm^{-3}) at a distance of 50,000 km from the nucleus.

The gaseous material of the cometary head is restored in a few hours at those velocities which are observed; the material of the tail is restored in a few days. If the amount of gas ejected from the nucleus in a time dt varies in inverse proportion to the square of the distance from the Sun, then in one revolution a periodic comet loses the following (since $r^2\frac{dv}{dt} = k\sqrt{p}$):

$$\int_0^P \frac{A dt'}{r^2} = \int_0^{2\pi} \frac{A dv}{k\sqrt{a(1-e^2)}} = \frac{2\pi A}{k\sqrt{a}\sqrt{1-e^2}}. \qquad (21)$$

Here the value $\frac{2\pi A}{k}$ expresses the amount of material evaporated by a comet of a certain absolute magnitude during the course of a year in moving along a circular orbit with radius of 1 AU.

If G is the instantaneous mass of the gaseous material of the head and complete renewal occurs in 24 hours (actually, it is apparently several times more rapid), then the comet loses the following in one revolution:

$$\frac{G \cdot 365{,}25}{\sqrt{a}\sqrt{1-e^2}} = \frac{G \cdot 365{,}25}{\sqrt{q(1+e)}} = G\Pi. \qquad (22)$$

Table 7 gives values of $G\Pi$ for certain periodic and short-period comets.

The nucleus loses even more mass as the result of the ejection of the dust matter. At present, the widely-acknowledged process for the ejection of the solid (high-melting) component is the evaporation of "contaminated ice", which was examined by F. Whipple [11]. An estimate of the mass of the dust matter was obtained from the data of spectrophotometry of the continuous spectrum of comets.

TABLE 7 /51

Comet	H_{10in}	Π	$G\Pi$, g
Encke	8	460	$4 \cdot 10^9$
Pons-Winnecke	8,6	313	$2 \cdot 10^9$
Daniel	6,7	247	$1,4 \cdot 10^{10}$
Neuimin I	9,9	221	$5 \cdot 10^{10}$
Halley	2	338	$3 \cdot 10^{12}$
Grant-Grigg-Milichius	3,7	299	$3 \cdot 10^{11}$

According to Whitney, the total mass of dust matter in the cometary head when its luminosity is due to reflection is the following:

$$\log M = \log \delta h + 2 \log \left[\frac{r\Delta \cdot 385 \cdot 10^5}{\Phi^{1/2}(\alpha)} \right] - 0{,}40m + 2{,}10; \qquad (23)$$

Here δ is the density in grams; h is the radius of the dust in cm; m is the apparent magnitude of the cometary head; Φ is the phase function describing the decrease in brightness at a phase angle of α with respect to the luminosity at $\alpha = 0$; r and Δ are expressed in AU.

For the tails of bright Comets 1957 III and 1957 V, M was on the order of 10^{14} g, i.e., 10^8 m, for $h = 0.3\mu$.

7. The Spectra of Comets and the Nature of the Parent Matter

The first visual observations of the spectra of comets are linked with the name of Donati of Florence. On August 5, 1864, Donati detected three wide bands in the spectrum of Comet 1864 II; he considered them to be similar to the spectra of metals. Subsequent observations of the spectra of other comets allowed Higgins to find that the cometary bands belong to the Swan spectrum (carbon spectrum), which produced the flame of a gas burner. At the same time, spectroscopic observations and examinations were being carried out by Sekki and Hasselberg (at Pulkovo).

The period of photographic and spectrographic observations of comets began in 1881; the presence of CN (cyanogen) bands in the violet region of the cometary spectra was discovered; sodium D lines were detected in Comet 1881 III, as well as in the bright Comets 1881 IV, 1882 I and 1882 II.

P. Swings calls the time from 1902 and 1939 the third period in the study of cometary spectra with cameras with an objective prism (Figs. 23, 24). A. Bom Pluvinel and F. Baldet in France,

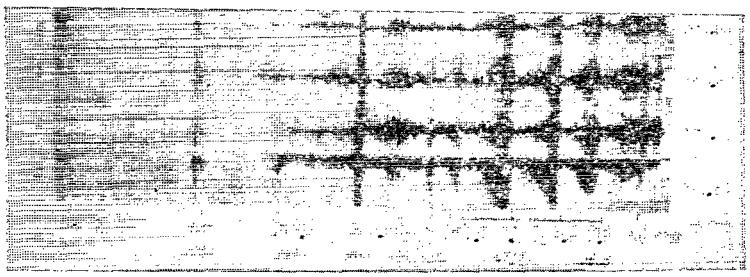

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Fig. 23. Slit Spectrograms of Comet 1941 I Cunningham in December of 1940 (P. Swings), Bands of C_2 and 3883 CN are Distinguished, as Well as the Intensive Continuous Spectrum of the Central Condensation.

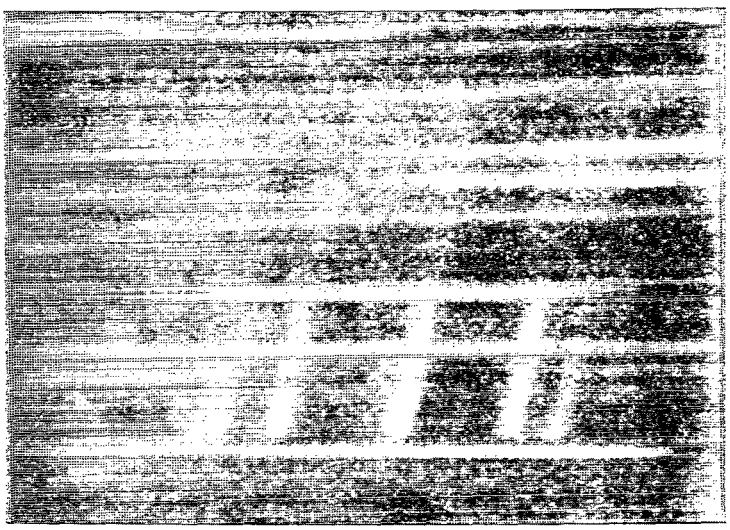


Fig. 24. Spectrum of Comet 1908 III Morehouse, Obtained with Objective Prism on October 18, 1908; the Tail CO^+ Emissions, and the Head C_2 and CN Emissions Can be Distinguished, with Almost Complete Absence of Continuum.

N. Bobrovnikoff in the USA, and Moscow astrophysicists S.N. Blazhko and S.K. Vsekhsvyatskiy studied the spectra of cometary tails. In /53

1909, A. Fowler showed that the brightest monochromatic emissions of the tails are generated by ionized molecules of carbon monoxide (CO^+), while the weaker sequence is produced by N_2^+ molecules. However, even fainter CO_2^+ emissions (ionized carbon dioxide molecules) were recently discovered in the spectrum of the tails.

An explanation of the nature of tails of the first type, the most active ones formed by great repelling forces, was of importance for understanding the characteristics of cometary processes. Bredikhin's suggestion that type I tails consist of hydrogen was found to be incorrect, although his idea that the division of tails into types was connected with the difference in specific weights or chemical affinity of the particles composing the tails has been corroborated.

The cometary material was found to consist of charged ionized particles-molecules combined with electrons, i.e., a plasma; consequently, all the processes which occur should obey the laws of electrodynamics.

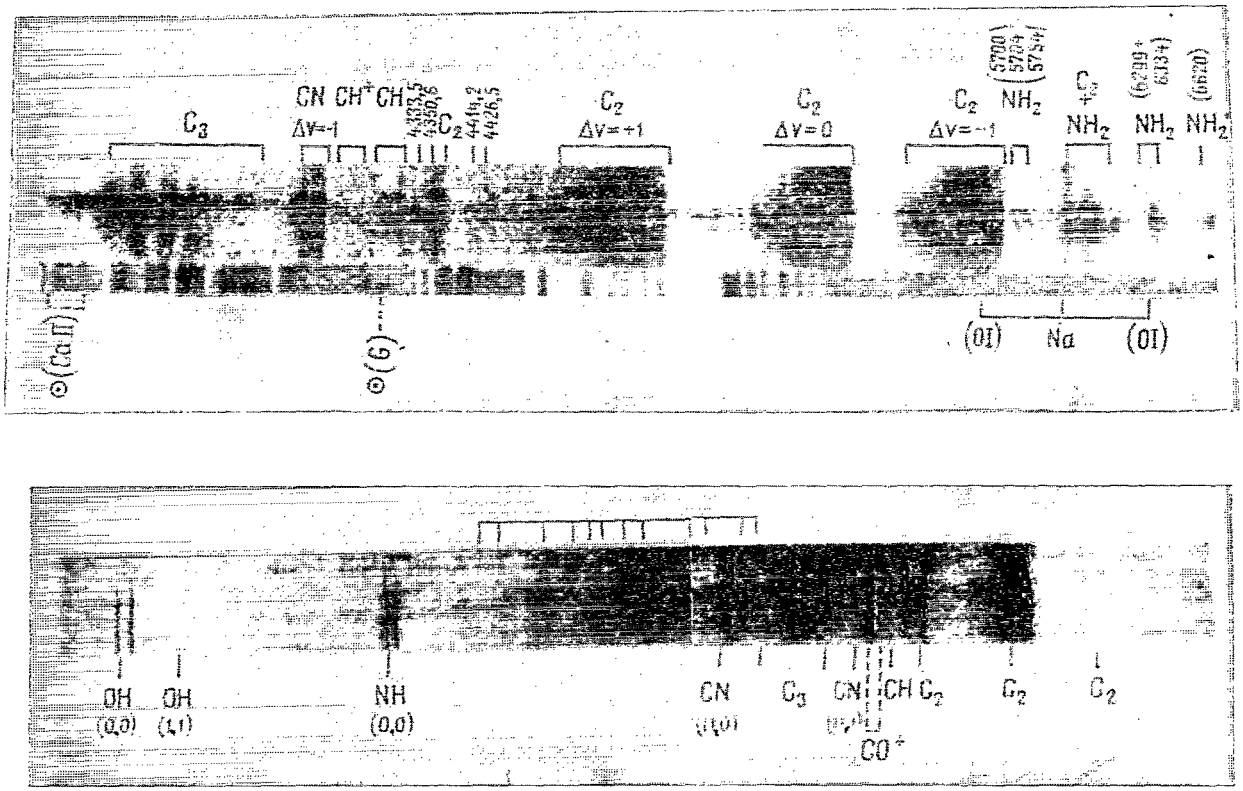
An investigation of the spectrograms of Comet Encke which were obtained by G.A. Tikhov at Pulkovo during three successive appearances allowed Vsekhsvyatskiy to establish that the spectrum of the comet changes very substantially from appearance to appearance, while the laws for the C_2 and CN density distribution in the head of the comet remain approximately unchanged.

At the beginning of the 40's, the presence of OH and NH bands whose structure corresponded to a low temperature was found in the spectra of Comet 1941 I; these bands were in the far ultraviolet, and could therefore be observed only when mirror telescopes and high-transmission diffraction spectrometers were used.

The bands of 4231, 4238 and 4254 Å in comets were identified as CH^+ emission. The NH_2 emission was found in the visual region, while more intense emission was found around 6300 Å.

After a special program studying the spectra of comets, Swings found that the intensity ratios $\frac{CN}{C}$, $\frac{C_3}{CH}$ and $\frac{C_3}{CN}$ increase systematically with an increase in the heliocentric distance of the comets.

Strong emissions around 7906 and 8106 Å were found in the infrared spectral region of the bright Comet 1947 XII. The assumption that they could correspond to the rotational-vibrational transitions of multiatomic molecules (NH_3, HCN, C_2H_2) cannot be accepted because of the absence of absorption bands produced by the processes of photodissociation in the ultraviolet. It was found that these infrared bands refer to the red CN system.



/54

Fig. 25. Spectrum of Comet Encke (according to Swings). Left: November 1, 1947 (3900-6630 Å Region); Right: October 17, 1947 (3090-5400 Å Region).

An investigation of the spectra of comets during this period /55 and a careful examination of the profiles of the CN 3870 and 3883 Å bands gave P. Swings and A. McKeller new proof of the resonance nature of the excitation of these emissions. The structure of the bands accurately reflected the effect of the Fraunhofer lines of the solar spectrum in this region, if the Doppler shift relative to the comet was considered, i.e., the radial velocity of the comet relative to the Sun. The same effect of radial velocity of the comet with respect to the Sun was then established for the CH, OH, NH and CH^+ bands.

Thus, when there are no collisions, the principal mechanism replenishing the population of the vibrational and rotational levels of the ground electron state of the molecules is the absorption of solar radiation. This can explain why the CH, OH, NH, CN and CH^+ bands show a rotational structure of the low-temperature type. The position is different in the case of homonuclear molecules of the $C^{12}C^{12}$ type: the purely rotational spectrum is forbidden for them, and the higher rotational levels are therefore filled, while the structure corresponds to high temperatures. However, this indicates that the terms "rotational and vibrational temperatures" are rather

conditional as regards the cometary bands.

High-power telescopes and spectrographs with high resolution began to be used in 1957 to obtain the spectra of bright comets. Substantial achievements have been made in this direction at the observatories of Mount Palomar, Kitt Peak, Haute Provence and Radcliffe.

A study of the cometary spectra yielded the following conclusions: together with the ordinary hydrocarbon components of cometary nuclei and heads with the emissions of CH, C_2, C_3, CH, OH, NH, CH_2 there are cases when the presentage of CO^+, CO_2^+ and N_2^+ is particularly high, as well as with nuclei with a substantial amount of gaseous Na and other interesting differences in the chemical affinity of the original, "parent" material; the Na is propagated in the direction of the tail from the nucleus to 500,000 km (Comet 1957 V); Swing's discovery of oxygen emission corresponding to the so-called forbidden transitions (red doublet 6300 and 6364 Å, green 5577 Å line) is repeated in the majority of the comets (Fig. 25).

The principal mechanism for the emission of cometary gases is the resonance fluorescence by the effect of solar radiation.

The Doppler shifts of the lines observed in the nucleus and head indicate that the particles acquire substantial initial velocities in the disintegration of the initial, parent molecules.

The restoration of the matter of the head, which is accelerated by the repulling force of the Sun, occurs (if r > 2-3 AU) in a few hours, while the matter of the tail of a bright comet is restored in a few days. /56

In many cases, a large amount of more massive particles producing the bright continuous spectrum of the head and nucleus, and often observed directly in the form of anomalous tails, is released together with the masses of gas from the cometary nucleus. There are serious reasons to assume that these are clouds of meteoritic particles which form meteoroid showers, according to the hypothesis of Schiaparelli-Bredikhin. However, it is not impossible that there are complex molecules or particles similar to snowflakes, which also can scatter the solar light and yield a continuous spectrum with Fraunhofer lines, in the comets. Finally, there could be a large number of electrons, which also scatter the light of the Sun, in the heads of comets.

The forbidden oxygen [10] lines are excited, obviously, by the mechanism of electron bombardment or the impact of solar protons. The comets which have particularly intensive emission of the CO^+ and N_2^+ bands (1908 III, 1962 VIII) are also found to be most active, with abrupt changes in the position of the tails, outbursts in the nucleus, etc.

Emissions corresponding to the isotopic $C^{12}C^{13}$ molecule (λ = 4744 Å) with content of $C^{13} > C^{12}$ have been detected in many bright comets.

Some emission bands in the heads and tails of comets have still not been identified. The density of the CN and C_2 molecules in the heads of comets, evaluated on the basis of photometric measurements, averages 10^4-10^5 per cm^3 near the nucleus and 1-10 mole/cm^3 at a distance of 100,000 km. For Comet Humason 1962 VIII, it was found that the concentration of CO^+ at a distance of 10,000 km from the nucleus was equal to 1000 molecules per cm^3 for concentration of CN of 15, and of N_2^+ of 10 molecules per cm^3.

An investigation of the oxygen [OI] emissions showed that, for bright comets, about 10^{30} molecules should be liberated per second, or $3 \cdot 10^8$ tons per month; this corresponds to a layer with thickness of 2.5 m, if the nucleus has radius of 10 km and low density.

The first investigations of the changes in spectra of comets were conducted by F. Baldet [12], N.B. Bobrovnikoff [13], and S.K. Vsekhsvyatskiy [14]. The principal contribution to the study of cometary spectra of a later period (30's and 40's, recently) was made by P. Swings [15] and his students. The studies of K. Wurm [16], B.A. Vorontsov-Vel'yaminov, O.V. Dobrovol'skiy, V.I. Cherednichenko and others had great significance in the interpretation of the spectra and explanation of the characteristics of the physical processes in the heads of comets.

8. The Ice in Cometary Nuclei /57

For a long time, it was assumed in studies of comets that the components of the head and tails of comets arise as a result of the liberation of a gas sorbed (absorbed) by meteoritic masses of the cometary nucleus.

The lumps of solid meteoritic matter, approaching the Sun, are heated, so that there is desorption of the gas inside them, just as in the heating of the matter of meteorites in an air-sealed vessel, when gas is released from it.

However, when the problem of the sorption of gases from cometary nuclei was formulated in the literature on comets, the Kiev astronomers raised the following questions:

(1) Can such energetic gas streams as we observe in bright, or active, comets be explained in this way?

(2) How should we understand the rather substantial stability of short-period comets, some of which were observed during tens of appearances?

(3) How can we explain the yield of complex hydrocarbon compounds on the surface of the cometary nucleus, when they disintegrate by the effect of solar photon or corpuscular radiation, as observed in a study of the cometary spectra?

As we have seen, the head of a comet is formed by masses of gas, the quantity of which is estimated as 10^{33} C_2 molecules (Halley's Comet at a distance of $r = 1$). The mass of the gas is completely replaced in a few hours, or much faster at shorter distances. There should be $\frac{dN}{dt} = 10^{29}$ molecules or $4 \cdot 10^6$ g which are released from the cometary nucleus in one second.

If the cometary nucleus is represented as a sphere of meteoritic matter with radius of 10 km, then its surface area is on the order of 10^{13} cm^2. The absorbed monomolecular C_2 layer on such a nucleus (on the basis of a diameter of the molecules of $3 \cdot 10^{-8}$ cm) should consist of $5 \cdot 10^{28}$ molecules, and, for the stream observed, for example, in Halley's Comet, should be desorbed in one second. The gas absorbed deep inside the nucleus cannot guarantee the requisite escape velocity. Moreover, observations show that comets have nebulous shells at distances greater than 10 AU, at a temperature where no desorption can occur.

If we assume that the nucleus consists of interplanetary dust, then the surface area of all the particles can reach 10^{21}-10^{22} cm^2 (for particle size 1μ); in this case, the quantity of molecules absorbed on the surface can reach 10^{36}, and can be liberated in 10^7 seconds.

However, this assumption cannot be made to agree with the high initial velocity observed for the gases leaving the nucleus, or with the fact that the cometary nuclei are largely stable. All that we /58
know from studies of the cometary spectra (when the absence of a continuous spectrum of the nucleus was observed repeatedly) and from the data on the chemical affinity of comets contradicts the models of dust nuclei: the radical observed in the head and nucleus doubtlessly arise as the result of the disintegration of the complex parent molecules, the absorption and desportion of which is quite improbable.

Other ideas have suggested a closer similarity between the cometary gases and the composition of the atmospheres of planets, particularly the giant planets.

In 1947, Vsekhsvyatskiy first suggested that the energetic outflows of gas from cometary nuclei, with effusions directed toward the Sun, can be understood only as the evaporation of different types of ice, as the sublimation of frozen methane-ammonium compounds which are in free state in the comets. The article entitled "The Problem of the Origin of Comets" (K voprosu o proiskhozhdenii komet, Astronomicheskiy Zhur., Vol. 25, No. 4, p. 265, 1948) substantiated this position.

Swings also concluded, independently, that there are different types of ice in cometary nuclei (when he was studying the spectra of Comet Encke). He suggested that the evaporation of different substances can explain the significant changes in the spectrum of a comet in different appearances which were noted by Vsekhsvyatskiy in 1938.

The problem of ice in the cometary nuclei was analyzed in detail by F. Whipple, in studies begun in 1950, when he suggested the theory of the "ice model" of cometary nuclei [17].

It was assumed in this theory that the nucleus of a comet consists of a mass of contaminated ice of complex hydrocarbon compounds, and is formed of separate particles.

Whipple showed that the release of gas due to sublimation of the ice is determined by the conditions of the heat conductivity on the surface of this dispersion system, and can be accompanied by high-melting particles which are entrained by the gas and which enter into the composition of the nucleus. The formation of meteoroid showers, which are similar to that of comets, can thus be explained.

If the nucleus rotates, then the maximum surface heating and, consequently, the greatest intensity of evaporation deviate from the direction toward the Sun; because of this, there can be both a decrease and an increase in the kinetic energy of the comet as a result of the reactive effect of the material leaving the nucleus.

A substantial layer of solid particles can be formed on the surface of the nucleus of old comets; this layer can prevent the evaporation of ice deep inside the nucleus and the release of gas. This can bring about the "secular" decrease in brightness of comets.

The substantial variety of the spectra of comets indicates that the "cometary model" is not universal. For example, despite almost sixty revolutions around the Sun since its discovery, one of the "oldest" comets, Comet Encke, still does not show any signs of /5
a continuous spectrum, although it lost more than 4^m in absolute brightness and diminished by a factor of 100. The surface area of the nucleus, which contained almost no meteoric particles, should have decreased by the same factor.

On the other hand, the bright Comets Arend-Roland 1957 III and Mrkos 1957 V, which released a large quantity of solid particles ($5 \cdot 10^{14}$-$7 \cdot 10^{15}$ g in one perihelion passage, according to Liller), showed good correlation to the ice model. These comets had an intensive continuous spectrum, and anomalous tails, where meteoric particles were observed directly. The diameters of the particles, which were obviously iron spheres, were on the order of 0.6μ.

Difficulties were also found in attempts at explaining the changes in motion of the comets on the basis of the initial representations of the ice model. D.O. Mokhnach showed that the acceleration or decelerations in the movement of comets can be the consequence of indefiniteness in the position of the photometric nucleus of the comet with respect to the center of mass. In 1963, Whipple suggested that the particles forming the dispersed body of the nucleus should have dimensions of no less than 1 cm and that the "ice model" does not explain the secular variations in the periods of comets.

We will return to this problem below, and we will attempt to show how the physical and kinematic characteristics of comets can be explained on the basis of the ice theory of cometary nuclei.

During the last 15 years, many researchers have examined the problem of the heating and sublimation of ice in comets. Swings and Delshemm pointed out that the parent molecules in the cometary ice could be in the form of hydrates. Only these frozen hydrates, including the H_2O molecule, could have a roughly identical heat of evaporation, and could sublimate at the average speed characteristic of the different types of tails [66].

After Whipple, Minnaert, Grushka, V. Cherednichenko, O. Dobrovol'skiy, M. Markovich, Z. Sekanina and others examined the thermodynamics of cometary nuclei consisting of contaminated or pure ice.

The following relationships are found between the quantity of incident heat Q/r^2, the albedo A, the radiation energy σT^4, the flux of heat inside the nucleus $-K(\text{grad } T)_0$ and the energy B consumed in evaporation from a unit surface in a unit time, for the surface of the nucleus:

$$(1-A)\frac{Q}{r^2} = -K(\text{grad } T)_0 + \sigma T^4 + B, \tag{24}$$

where Q is the solar constant and K is the coefficient of thermal conductivity of the material of the nucleus.

If α is the coefficient of evaporation and p is the saturation vapor pressure, $L = (c_p - c)T_0 + L_0$ is the heat of evaporation of one particle at temperature of T_0, then /60

$$N = \frac{B}{L} = \frac{\alpha p}{\sqrt{2\pi MkT_0}}, \tag{25}$$

where M is the mass of the molecule; L_0 is the heat of evaporation at 0°K; c_p is the heat capacity of the vapor under constant pressure; c is the heat capacity of the material of the nuclear surface.

Obviously, the value of N is equal to the number of particles sublimating per unit surface per unit time.

Furthermore,

$$p = aT_0^{\frac{c_p - c}{k}} e^{-\frac{L}{kT_0}} \tag{26}$$

(a is constant and k is the Boltzmann constant).

Using these ratios instead of the heat-conductivity equation, i.e.,

$$\rho c \frac{\partial T}{\partial x} = \frac{\partial}{\partial x}\left(K \frac{\partial T}{\partial x}\right), \tag{27}$$

M.Minnaert and later M. Markovich found that the temperature of the conditional nucleus of Halley's Comet can reach 330°K at perihelion and can decrease to 50° at aphelion; the curve is not symmetric with respect to the perihelion. Approximating the data of calculations by the formula $T_0 = T_{0.0} r^{-n_0}$, where $n_0 \leq \frac{1}{2}$, Markovich found that the apparent magnitude of the comet reduced to a unit distance from the Earth is approximately equal to the following:

$$m_\Delta = C + Dr^{-n_0} \tag{28}$$

(C and D are constant).

Vsekhsvyatskiy [18] had suggested this formula for the brightness curve of comets, as a function of the heliocentric distance, in 1936. Later, it was examined by B. Yu. Levin in connection with the problem of the suggested mechanism for the desorption of gases from the solid body of the nucleus. The emissions of the radicals CN, C_2, NH, NH_2, CH, CH^+, N_2^+, CO^+, C_3, OH^+, CO_2^+, as well as Na atoms at substantial distances, which were observed in the spectra of comets showed rather certainly that there is ice of H_2O or CO_2, NH_3, CH_4, C_2H_2, and also hydrates and molecules of sodium salts which sublimate easily even at substantial distances from the Sun in the nuclei of comets.

For comets whose nuclei (diameter of 0.25 km) consist of pure ice of the cited compounds, the life span in the form of comets (i.e., before complete evaporation of the ice) is about 100 years if q = 0.5 AU and a = 3 AU. The shortest life span under otherwise equal conditions should occur for ice of NH_3 and C_2H_2; ice of CH_4 and CO_2 should have the longest life span. Comets with a = 18 AU and q = 4 AU can exist for more than 10,000 years if the diameter of the nucleus is 1 km.

PART II

THE ORIGIN OF COMETS

9. Contemporary Theories and Their Correspondence With the Data on the Motion and Nature of Comets

We have already mentioned (Part I) that, after Laplace and /61
Lagrange set forth opposing points of view on the origin of comets at the beginning of the 19th century, most astronomers were sympathetic to Laplace's idea that comets come from interstellar space. At the same time, the development of specific probability problems in the field of cometary astronomy, investigations on the problem of large-scale disturbances to explain the characteristic aspects of the system of short-period comets, and calculations of the original orbits of near parabolic comets have led to definite conclusions which do not further Laplace's hypothesis.

In the 1880's, R. Proctor gave his active support to the idea of the disruption or burst of a planet, as did Crommelin in 1910-1914, but their voices were lost against the background of different opinions.

At the beginning of the 1930's, Vsekhsvyatskiy presented new arguments in favor of the eruptive origin of comets: the secular decrease in brightness of short-period comets, showing that they are not old; the chemism of comets, which is similar to the chemism of planetary atmospheres; the existence of close approaches to the Jupiter system before discovery of the comets, etc. It was acknowledged at this time that comets should accompany the solar system in its movement in space, forming a unique cloud around the Sun, as first concluded by Schiaparelli. Many discrepancies were found in the conclusions of the capture theory (which was widely developed in the studies of H. Newton, Callandro, Schulhof, Tisserand, etc.) with regard to the data of cometary astronomy. However, the need for assuming that there were high initial velocities in the eruptions from the surface of planets scared most astronomers because of the very large scales of these cosmic cataclysms; the concept of an eruption raised a great deal of criticism, but this theory is not found in the investigations of active researchers.

During this time, because of the arguments of G. Russel and /62
V.G. Fesenkov against the disruption hypotheses on the origin on the planetary system, the hopes of the condensation cosmogonies were very high, and there was a large number of variations of different nebular, or meteoritic, hypotheses. In the hypotheses of Weizsacker, Kuiper, O. Schmidt, Fesenkov, Whipple and others, the comets were attributed the third-degree role of the remains of the original matter used in the formation of planets.

In 1950, J. Oort suggested that comets have clouds which move near the boundaries of the solar system (25-150 thousand AU). Oort assumed that the entire system of comets, asteroids, meteorites and meteors were formed as the result of the eruption of a planet.

It was assumed in subsequence cosmogonies that the comets were condensed in a region at the boundary of a system of planets 40-50 AU from the Sun (Kuiper, 1951), or in other regions (Whipple, 1963) of the original Laplace or Weizsacker nebula. Oort recently rejected the concept of eruption of a planet; he now considers it possible that small condensations arose in the original stage of development of planets. These small condensations, or comets, could be directed by the effect of planetary disturbances into the region of a cometary cloud, where they remain for a long time [19].

These hypotheses follow from the principle assumption regarding the condensation of planets from some original material. However, this original position is not discussed in the light of rapidly supplemented data on stellar cosmogony and observations of planets, but is accepted by tradition without any question. At the same time, it is in marked contradiction with the data on the very large-scale processes in the star system and in the galaxy system. The methodology for the speculative definitions which is found in the majority of studies on the cosmogonies of the solar system is often very different from that approach by which the processes of the development of stars and stellar systems are investigated. The principle here is to analyze observations, whereby it is concluded that the processes of decay and disintegration of galactic and metagalactic objects play the determinant role. Obviously, no indisputable case where scattered material is combined can be cited; the "nebular" diffuse material we have observed is formed mainly as the result of the ejection of matter from stars and stellar systems.

Another characteristic must be mentioned: in the majority of cosmogonic hypotheses on comets, there is an explicit or implicit assumption that there is a radical difference between comets and other small bodies, for example, meteorites and asteroids, as regards their nature.

In the 1950's Lyttleton suggested a new variation of the interstellar hypothesis of the origin of comets: the gravitational focusing of particles of interstellar dust and the resultant condensation of comets. This pattern was not supported, since it did /63 not correspond to any characteristics of the complex of comets of which we know. Neither the distribution of aphelion directions, the presence of ice in the comets, or the stability of comets indicate that Lyttleton's pattern might be correct.

In 1963, Fesenkov made an attempt to return to the interstellar hypothesis, also assuming that the comets were in the form of a cloud of particles, but these particles were more similar to snowflakes than dust particles; at the same time, he presented many arguments

in 1952 to support Orlov's idea of the destruction of planets producing asteroids, meteorites and comets.

Convincing proof of the affinity of cometary and planetary matter, of the characteristic nature and motion of asteroids, meteorites and comets, has been obtained during the last twenty years, as well as arguments in favor of the cometary-meteoritic nature of the rings of Saturn and the proposed ring of Jupiter.

It is not only the continuous spectrum observed in many comets which indirectly proves that there are meteoritic masses in the nuclei of comets, but also the substantial stability of a number of comets undergoing the high-energy effect of the tide-generating forces of the Sun or planets.

In 1808, Calandrelli, and later Schiaparelli, Charliet, L. Picard, Tisserand and Svoboda derived the criteria for the instability of a meteor cluster or the nucleus of a comet; for example, the following ratio was obtained:

$$M_{\mathrm{C}} = \frac{(3+e)\,M_{\odot} R_{\mathrm{C}}^{3}}{q^{3}}, \qquad (29)$$

where M_{C}, M are the masses of the comet and the Sun, respectively, R_{C} is the radius of the cometary nucleus, e and q are the eccentricity and perihelion distance of the cometary orbit.

The use of this ratio gave the upper limit to the mass of a comet for a given R_{C}. However, the dimensions of cometary nuclei can be estimated only in a few exceptional cases.

The great variety in the nature of the spectra, the quantity of gaseous material and the absolute magnitude, as well as the activity of the comets, etc., all show that there are differences in the structure of comets, the chemism, the ratio between low-melting and high-melting components, the state of the frozen gases, which can also obviously be in the form of solid ice and in the form of slightly cemented snow piles. This is all means that the formation of comets could not occur by way of slow condensation in the rarefied interplanetary medium, where all the characteristics should have been averaged over the millions of years. It is obvious that the formation of complex molecules also could have occurred only on the surface of cooling planetary bodies, under substantial /64 pressures and temperatures.

Undoubtedly, the comets should have descended to the Earth's surface many times, since we now know of many more comets approaching the Sun at a distance less than 1 AU than asteroids. However, we will not divide meteorites into those formed from planetary matter and the original ones. In any case, after studying the descents we will obtain confirmation of the planetary nature of the

matter precipitated from space.

Consequently, in addition to ice and meteoric particles, cometary nuclei should also include the ordinary meteoritic masses in many cases.

Comet Ikeya-Seki 1965f, which passed through the intercorona of the Sun on October 21, 1965 and showed a spectrum similar to that of meteoritic matter, gave strong support to the idea that there are meteoritic masses in comets.

Thus, only two possibilities remain: the knowledge that comets are either the product of disintegration of planetary body, or are formed from the "original" material or the remains of certain planets which existed before the origin of our solar system.

However, this "two-stage" evolution of the matter of the solar system is not confirmed by a determination of the absolute age of numerous meteorites we know, and there obviously was not enough time after the development of the elements for it. The authors of the cited cosmogonic hypotheses also pass over an obvious contradiction, when the condensation of matter is assumed to be the result of cosmic collisions for comets, while eruptions of the surface and ejection of planetary (meteoric) matter due to stream collisions are postulated as the reason for the appearance of meteoritic matter and meteorites.

It is not explained in these hypotheses how complex hydrocarbons and cometary radicals could arise in the original cometary nuclei in the form of very substantial reserves of ice. We know that complex molecules are formed in the atmosphere of stars, while the ice is formed on the surface of planets; it can also be assumed to be on the surface of cold stars. However, no one has observed ice in interplanetary or interstellar space.

Even if additional assumptions are made to answer these questions, it is still an insurmountable difficulty to explain the formation of families of short-period and periodic comets and the specific characteristic of the Jupiter family. The existence of 75 comets with periods shorter than 13 years with exceptionally straight forward motion, rapidly disintegrating, cannot be explained on the basis of the theory of "capture" or diffusion of comets.

We can prove that this is impossible by examining the curve /65
for the distribution of comets over log P or log a (see Fig. 1).

The distribution of comets over log P is characterized by a sharp maximum 0.7-0.8 (Jupiter family) and small maxima corresponding to other comet families. This nature of the curve shows that there is no steady state in the system of comets, and can be a convincing proof against the theory of capture (or diffusion) of comets.

The extent to which the cometary curve differs from that distribution which should have occurred according to the plans of Oort or Fesenkov is shown by a comparison with the curve for the formation of different cometary orbits according to the capture theory; this curve is given on the same figure.

The maxima corresponding to the planet families of periodic comets (particularly the maximum of the Jupiter family) cannot be attributed to the conditions of observational selection, since we have roughly identical visibility ranges corresponding to $q < 2$-3 AU in each case (to log $P = 3$). The total number of transformed orbits should be proportional to $P^{4/3}$ or a^2 for each of the effective disturbance centers. However, Jupiter should have the greatest effect, since the probability of the corresponding transformations of the orbits is at least 35 times less in the case of Saturn, for example. Considering that the rate of disintegration is in inverse proportion to some degree of P, we find that the theoretical curve ascends more steeply toward high values. Therefore, the number of comets with low P cannot be explained within the framework of the equilibrium model. All of these comets should have been formed in the central regions of the solar system relatively recently.

No less convincing conclusions can be obtained from an examination of the distributions of orbital inclinations. These distributions are given in Figure 4 for the combination of the same 577 comets, and for different comet families and groups.

Here, there is an ordered transition from the planetary type of movements of the comets of the Jupiter family through groups (it is true that there is sometimes very few) with decreasing predominance of straight forward motion (group of Saturn, Uranus, Neptune, Group P = 100-500 years) to an almost symmetric distribution over i for long-period and near parabolic comets.

The absence of retrograde motion in the system of short-period comets can serve as an independent proof that they were formed recently. At the same time, it shows the significant rate of disintegration (i.e., fading) of comets which have rather short return periods. The latter follows from the fact that we do not see one case in systems of comets with $P < 50$ years where the comet can be considered to be transformed (captured) from the field of long-period comets. /66

Thus, the standard hypothesis (of Kuiper, Whipple, Oort etc.) on the origin of comets contradicts the facts.

10. The Laplace Problem

Assuming that there were definite conditions existing in a hypothetic swarm of interstellar comets, Laplace concluded in 1805 that there was high probability of elliptical orbits and low proba-

bility of hyperbolic orbits [20].

Laplace's conclusions agreed extremely well with what was known about the movement of comets at that time. All the comets, except for Halley's Comet and the short-period Comet Lexell, moved along orbits which, practically speaking did not differ from parabolas. Laplace's conclusion was seen as a confirmation of the idea that comets come from outside the solar system.

Laplace later wrote on this theme in "Exposition du système du monde"; "According to our hypothesis, comets do not belong to the solar system. Taking them for small nebulae travelling from one solar system to another and forming as the result of the condensation of the nebulous matter, which is usually poured over the universe, we see how they reach that part of space in which the solar attraction is predominant, causing them to describe elliptical or hyperbolic orbits...

...Determining by analysis of the probabilities the relationship between the chances giving an indisputable hyperbola and the chances of a curve similar to a parabola, I found that it is 6,000 to 1 that a nebula penetrating into the effective sphere of the Sun, so much that it can be observed, will describe either a very extended ellipse, or a hyperbola, which would almost coincide in the magnitude of its axis with the parabola in the part of the orbit accessible to observations; therefore, it is not surprising that hyperbolic motions have still not been noted"[10].

As was shown by the studies of Schiaparelli, Nissel, Fabry and later N.D. Moiseyev, Laplace's conclusion was erroneous. Fabry wrote the following in his memoir[11]: "A theoretical calculation leads to a result which is directly opposite to that obtained by Laplace; i.e., so the exceptionally high probability of hyperbolic orbits in the intersteller origin of comets is assumed. However, the motions of comets which have been observed do not give us anything like that".

The correctness of this conclusion can be seen in the following /67
fundamental concepts: the relative velocities belonging to the solar system are equal to $v = 30\sqrt{\frac{2}{R} - \frac{1}{a}}$ (km/sec) at a distance of R, if a and R are measured in AU. At a distance of 100,000 AU, the relative velocities of solar comets are less than 0.1 km/sec. At the

[10] Klassicheskiye kosmogonicheskiye gipotezy (Classic Cosmogony Hypotheses). Sbornik. Collection: Seriya "Kossiki Yestestvoznaniya", Moscow, "Gisizdat", 1924, pp. 65-66.

[11] Fabry, L.: Etude sur la probabilite des cometes hyperboliques et l'origine des cometes (Study on the Probability of Hyperbolic Comets and the Origin of Comets). Marseilles, 1893.

same time, the velocities of hypothetic "interstellar" comets should correspond to the velocities of the stars, i.e., tens of kilometers per second.

What orbits should be observed for these interstellar comets? Assuming that $v \approx 30$ km/sec at the boundary of the solar system (100,000 AU), we find that $\frac{2}{100000} - \frac{1}{a} = 1$, so that $a \approx -1$.

We observe comets near the Sun if their perihelion distances are on the order of 1-2 AU, i.e., when $q = a(1 - e) \approx 1$. Considering the value $a \approx -1$, we find that for interstellar comets, the eccentricity of these orbits should be equal to 2 or more; i.e., the order should be distinctly hyperbolic. In reality, we do not observe such orbits.

Fabry concluded that comets should belong to the solar system, as members of the latter Fabry went even further in this direction than Schiaparelli, who, being the first to find Laplace's error, assumed that the comets form a "comet swarm" accompanying the solar system in its movement in space. In our time, this "comet swarm" of Schiaparelli is called the "comet cloud" of Oort.

How was the Laplace problem solved and how was the inaccuracy of his conclusions determined?

Laplace sssumed that the solar system is stationary, on the average, with respect to the entire system of comets, i.e., that it does not have motion relative to the stars (during Laplace's time, nothing was known of the motion of the Sun); however, Laplace suggested initial conditions in the complex of comets which are absolutely false.

Let us imagine a point C at a distance of R from the Sun S at the boundary of the effective sphere of the Sun[12]; we will take this point as the origin of the coordinates x, y, z (the x axis is directed toward the sun) [68].

Let u, v, w be the components of the relative velocity of the comets, which is near the point C. In the velocity space, they determined the position and direction of the comet's velocity $V = \sqrt{u^2 + v^2 + w^2}$. The distribution $\phi(u, v, w)$ characterizes the density of the point of the velocity vectors in the velocity space near point C, while the probability that the values of the components will be within the range of $u \pm \frac{1}{2} du$, $v \pm \frac{1}{2} dv$, $w \pm \frac{1}{2} dw$ is equal /68 to $(u, v, w)\, dudvdw$.

[12] The effective sphere of the Sun is that region where the attraction of the Sun overcomes the attraction of both the neighboring stars and the center of the galaxy.

Producing the average values of the velocity components $\bar{u}$, $\bar{v}$ $\bar{w}$, and dispersons σ: $N\sigma_1^2 = \Sigma(u - \bar{u})^2$; $N\sigma_2^2 = \Sigma(v - \bar{v})^2$; $N\sigma_3^2 = \Sigma(w - \bar{w})^2$ (N is the total number of comets), we can examine a few assumptions.

First assumption (Laplace): $\bar{u} = \bar{v} = \bar{w} = 0$; $\phi(u, v, w) = \frac{K}{V^2}$ (K is sum constant).

Here the Sun is considered to be fixed relative to the entire system of comets, and the comets which do not move at the initial moment relative to the Sun have the highest probability (equal to infinity).

Second assumption:

$$\bar{u} = \bar{v} = \bar{w} = 0; \quad \varphi(u, v, w) = L = \text{const};$$

Third assumption:

$$\bar{u} = \bar{v} = \bar{w} = 0; \quad \varphi(u, v, w) = Ce^{-\frac{u^2+v^2+w^2}{2\sigma^2}};$$

Fourth assumption: $\bar{u}$, $\bar{v}$, $\bar{w}$ are not equal to 0.

If we convert to the polar coordinates V, β, l, then the element of the volume in the velocity space is expressed thus: $dudvdw = V^2 dV d\beta \sin \beta dl$. The probability that V, β and l will be within the range of $V \pm \frac{1}{2} dV$, $\beta \pm \frac{1}{2} d\beta$, $l \pm \frac{1}{2} dl$, is equal to the following for the first assumption:

$$\frac{K}{V^2} V^2 dV\, d\beta \sin \beta\, dl = K dV\, d\beta \sin \beta\, dl. \tag{30}$$

It is obvious that

$$\int_0^M \int_0^\pi \int_0^{2\pi} K dV\, d\beta \sin \beta\, dl = 1, \tag{31}$$

If M is the maximum permissible value of V. Therefore

$$KM4\pi = 1 \text{ and } K = \frac{1}{4\pi M}.$$

Similarly, we find the following for the second case:

$$L\frac{4}{3}\pi M^3 = 1 \text{ and } L = \frac{3}{4\pi M^3}.$$

For the conditions of the third assumption, the fundamental

probability is expressed as $Ce^{-\frac{V^2}{2\sigma^2}} V^2 dV d\beta \sin\beta dl$, and we find with integration that

$$C\int_0^{\infty} V^2 e^{-\frac{V^2}{2\sigma^2}} dV \int_0^{\pi} \sin\beta\, d\beta \int_0^{2\pi} dl = 1 = \frac{C}{2} V\overline{2\pi}\sigma^3 \cdot 2 \cdot 2\pi, \qquad (32)$$

/69

from which

$$C = \frac{1}{\sigma^3 (2\pi)^{\frac{3}{2}}}. \qquad (33)$$

Since the probability of values of V, β and l is equal to $f(V)dVd\beta \sin\beta dl$,

then for the first approximation $f(V) = \frac{1}{4\pi M}$;

for the second, $f(V) = \frac{3V^2}{4\pi M^3}$;

for the third, $f(V) = \frac{V^2 e^{-\frac{V^2}{2\sigma^2}}}{\sigma^3 (2\pi)^{\frac{3}{2}}}$.

Of all the possible comets at the point C, we are interested only in those which can be observed from the Earth; i.e., which are in the "visibility sphere".

Laplace assumed that 11 of the comets which have perihelion distance of $q < 2$ are "visible". The problem is now reduced to that of determining what number of comets, of all the "visible" ones, have elliptical, parabolic and hyperbolic orbits.

Taking the Gaussian constant as equal to 1, and expressing the length in astronomical units and the times in units of $\frac{\text{year}}{2\pi} = 58.13$ days, we will find the integral of kinetic energies in the form of $V^2 = \frac{2}{r} - \frac{1}{a}$ (a is the semiaxis of the cometary orbits). The integral of the areas have the following form: $\sqrt{a(1 - e^2)} = Vr\sin\beta$. Here β is the angle of the velocity vector with the radius or the x axis as well as the u axis.

Therefore

$$V\sin\beta = \sqrt{v^2 + w^2} \text{ and } u = V\cos\beta.$$

Since $a(1 - e^2) = q(2 - \frac{q}{a})$ and $u^2 + v^2 + w^2 = V^2$, then, using

the designation $Q = \frac{q}{r}$ and $R = \frac{2}{r}$, we find the following:

$$V^2 = R - \frac{1}{a} \tag{34}$$

and

$$v^2 + w^2 = Q\left(R - \frac{Q}{a}\right). \tag{35}$$

Eliminating a from (34) and (35), we find that /70

$$-Q^2u^2 + (1-Q^2)v^2 + (1-Q^2)w^2 = RQ(1-Q) \tag{36}$$

or

$$-\frac{u^2}{A^2} + \frac{v^2}{B^2} + \frac{w^2}{B^2} = 1; \tag{37}$$

This is the equation of the hyperboloid of rotation around the x axis, which separates the "visible" comets; in this case

$$A^2 = \frac{R}{Q}(1-Q) \text{ and } B^2 = \frac{RQ}{1+Q}. \tag{38}$$

All comets going out of point C which yield orbits with perihelion distance of q have end-points of the velocity vectors on the surface of the hyperboloid; each point on the surface of the hyperboloid of visibility corresponds to initial velocities which yield orbits with perihelion distance of q.

Schiaparelli showed that different q correspond to coaxial isogonal hyperboloids in the velocity space, and that each velocity corresponding to some point inside the hyperboloid relates to a perihelion distance less than q. Consequently, the comets which are in the visibility sphere are bounded by the limit hyperboloid, which corresponds to $q = 2$, i.e., to the condition $Q = R$.

The region inside the hyperboloid is divided by the surface of a sphere with radius of $V = \sqrt{R}$ into two regions; one of elliptical orbits and one of hyperbolic orbits.

In Figure 26, this hyperboloid is depicted in cross section by a plane passing through its axis of rotation. The region bounded by the surfaces of the sphere and hyperboloid (E) gives elliptical orbits; the region outside the sphere and inside the hyperboloid (H) yields the hyperbolas.

If $V > B$ (B is the value of the radial axis of the hyperbolas), then the probability that the values of V will be within the range of $V \pm \frac{1}{2} dV$ is determined by the following integral:

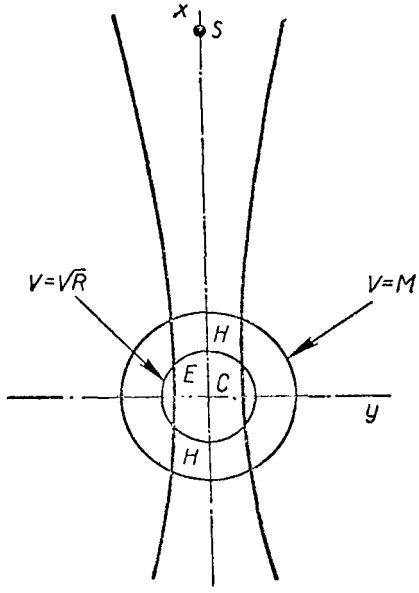


Fig. 26. Schiaparelli's Hyperboloid of Visibility.

$$f(V)\,dV \int_0^{\pi} d\beta \sin\beta \int_0^{2\pi} dl = 4\pi f(V)\,dV. \qquad (39)$$

If $V > B$, then integration must be carried out only over the surface of circle caps, which are determined by the value of β corresponding to the point of intersection between the sphere and the hyperboloid of visibility. However, $\cos\beta = u/V$, while we find from the equation of the hyperboloid that /71

$$\frac{u^2}{V^2} = \frac{A^2}{A^2 + B^2}\left(1 - \frac{B^2}{V^2}\right) = (1 - Q^2)\left(1 - \frac{B^2}{V^2}\right), \qquad (40)$$

Therefore $2f(V)\,dV \int_0^{\beta} d\beta \sin\beta \int_0^{2\pi} dl =$

$$= 4\pi f(V)\,dV\,(1 - \cos\beta) = 4\pi f(V)\,dV\left(1 - \sqrt{1 - Q^2}\cdot\sqrt{1 - \frac{B^2}{V^2}}\right). \qquad (41)$$

Consequently, the probability of visible comets is equal to the following:

$$P = 4\pi \int_0^B f(V)\,dV + 4\pi \int_B^M f(V)\,dV\left(1 - \sqrt{1 - Q^2}\cdot\sqrt{1 - \frac{B^2}{V^2}}\right) =$$

$$= 4\pi \int_0^M f(V)\,dV - 4\pi\sqrt{1 - Q^2}\int_B^M \sqrt{1 - \frac{B^2}{V^2}}\,f(V)\,dV. \qquad (42)$$

Since elliptical orbits correspond to the condition $V < \sqrt{R}$, then

$$P_{el} = 4\pi \int_0^B f(V)\,dV + 4\pi \int_B^{\sqrt{R}} f(V)\,dV\left(1 - \sqrt{1 - Q^2}\cdot\sqrt{1 - \frac{B^2}{V^2}}\right). \qquad (43)$$

Correspondingly, the probability of hyperbolic orbits is expressed by the following:

$$P_{\text{hyp}} = 4\pi \int_{\sqrt{R}}^{M} f(V)\, dV \left(1 - \sqrt{1-Q^2}\cdot \sqrt{1-\frac{B^2}{V^2}}\right) =$$

$$= 4\pi \int_{\sqrt{R}}^{M} f(V)\, dV - 4\pi\sqrt{1-Q^2} \int_{\sqrt{R}}^{M} \sqrt{1-\frac{B^2}{V^2}} f(V)\, dV. \qquad (44)$$

Obviously, the relative probabilities are equal to: /72

$$p_{\text{el}} = \frac{P_{\text{el}}}{P}; \quad p_{\text{hyp}} = \frac{P_{\text{hyp}}}{P},$$

$$p_{\text{el}} + p_{\text{hyp}} = 1.$$

We can use the substitution $y^2 = V^2 + B^2$ in the second integral of (42), so that

$$dV = \frac{y\,dy}{\sqrt{y^2+B^2}}; \quad 1 - \frac{B^2}{V^2} = \frac{y^2}{y^2+B^2}.$$

For the first case, we found that $f(V) = \frac{1}{4\pi M}$; therefore, integration gives the following:

$$P_{\text{el}} = \frac{\sqrt{R}}{M} - \frac{1}{M}\sqrt{1-Q^2}\left(\sqrt{R-B^2} - B\arctan\frac{\sqrt{R-B^2}}{B}\right);$$

$$P_{\text{hyp}} = 1 - \frac{\sqrt{R}}{M} + \frac{1}{M}\sqrt{1-Q^2}\left(\sqrt{M^2-B^2} - \sqrt{R-B^2} - \right. \qquad (45)$$

$$\left. - B\arctan\frac{\sqrt{M^2-B^2}}{B} + B\arctan\frac{\sqrt{R-B^2}}{B}\right);$$

$$P = 1 - \frac{1}{M}\sqrt{1-Q^2}\left(\sqrt{M^2-B^2} - B\arctan\frac{\sqrt{M^2+B^2}}{B}\right).$$

Since

$$\sqrt{R-B^2} = \frac{\sqrt{R}}{\sqrt{1+Q}} \text{ and } \frac{\sqrt{R-B^2}}{B} = \frac{1}{\sqrt{Q}},$$

and in view of the low value of Q and $\arctan\frac{1}{\sqrt{Q}} = \frac{\pi}{2} - \arctan\sqrt{Q}$, we can find the following expressions for the probabilities, keeping only those terms which contain Q to a power less than 2, and assuming that $\arctan\frac{M}{B} = \frac{\pi}{2}$;

$$P = \frac{\sqrt{RQ}}{M}\cdot\frac{\pi}{2}; \quad P_{\text{el}} = \frac{\sqrt{RQ}}{M}\left(\frac{\pi}{2} - \frac{\sqrt{Q}}{2}\right); \quad P_{\text{hyp}} = \frac{0\sqrt{R}}{2M} \qquad (46)$$

or

$$p_{el} = 1 - \frac{\sqrt{Q}}{\pi}; \quad p_{hyp} = \frac{\sqrt{Q}}{\pi}.$$

Since the value of $\sqrt{Q}$ is very small, the probability of elliptical orbits is found to be close to 1, while the probability of hyperbolas is close to 0, which corresponds to Laplace's conclusions. If we consider terms of higher orders relative to Q, we find practically the same results. If $M \to \infty$, then the result is the opposite.

We have already mentioned that the Laplace function of velocity distribution is completely arbitrary and hardly probable; therefore, we must examine other cases. /73

For the second assumption $f(V) = \frac{3V^2}{4\pi M}$; substituting this function into (42), (43), (44) and replacing $V^2 = y^2 + B^2$ and $R - B^2 = \frac{R}{1+Q}$, we find the following:

$$P_{el} = R^{\frac{5}{2}} M^{-3} \left(1 - \frac{\sqrt{1-Q}}{\sqrt{1+Q}}\right); \quad P_{hyp} = P - P_{el};$$
$$P = 1 - \sqrt{1-Q^2}\left(1 - \frac{B^2}{M^2}\right)^{\frac{3}{2}}. \qquad (47) \qquad (47)$$

Expanding these expressions into series in powers of Q and V and eliminating terms with powers higher than 2, we can obtain the following expressions, if we assume that $R = Q$ and if we disregard the term B^2/M^2:

$$P_{el} = \frac{3}{2} Q^{\frac{5}{2}} M^{-3}; \quad P = \frac{1}{2} Q^2; \quad P_{hyp} = \frac{1}{2} Q^2 - \frac{3}{2} Q^{\frac{5}{2}} M^{-3}. \qquad (48)$$

Therefore,

$$p_{el} = \frac{3\sqrt{Q}}{M^3}; \quad p_{hyp} = 1 - \frac{3\sqrt{Q}}{M^3}.$$

Since Q has a value on the order of 10^{-5} and M in our units can reach several tens (maximum velocities of the stars relative to the Sun on the order of 500 km/sec), then p_{el} proves to be a small value on the order of 10^{-5}, while p_{hyp} is practically equal to one. This result is the opposite of Laplace's results, since he assumed that the density of the end point of the vectors in the velocity space decreases with an increase in distance from the center C.

For the third assumption, it is most natural to consider the Gaussian distribution of velocities, so that we obtain the following when $M \to \infty$ and $V^2 = y^2 + B^2$:

$$P_{\text{el}} = \int_0^{\sqrt{R}} \frac{2V^2}{\sigma^3\sqrt{2\pi}} \cdot e^{-\frac{V^2}{2\sigma^2}} dV - \sqrt{1-Q^2} \int_0^{\sqrt{R-B^2}} \frac{2y^2}{\sigma^3\sqrt{2\pi}} e^{-\frac{y^2+B^2}{2\sigma^2}} dy,$$

$$P_{\text{hyp}} = \int_{\sqrt{R}}^{\infty} \frac{2V^2}{\sigma^3\sqrt{2\pi}} \cdot e^{-\frac{V^2}{2\sigma^2}} dV - \sqrt{1-Q^2} \int_{\sqrt{R-B^2}}^{\infty} \frac{2y^2}{\sigma^3\sqrt{2\pi}} \cdot e^{-\frac{y^2+B^2}{2\sigma^2}} dy, \tag{49}$$

$$P = \int_0^{\infty} \frac{2V^2}{\sigma^3\sqrt{2\pi}} \cdot e^{-\frac{V^2}{2\sigma^2}} dV - \sqrt{1-Q^2} \int_0^{\infty} \frac{2y^2}{\sigma^3\sqrt{2\pi}} \cdot e^{-\frac{y^2+B^2}{2\sigma^2}} dy.$$

Thus, /74

$$P = 1 - \sqrt{1-Q^2} \cdot e^{-\frac{B^2}{2\sigma^2}}. \tag{50}$$

If we use a certain value of the integral as

$$\int_0^{\infty} \frac{2x^2}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{x^2}{2\sigma^2}} dx = \sigma^2,$$

then, expanding the integrand into a series and assuming that $R = Q$ and $B^2 = RQ = Q^2$, we obtain the following:

$$P_{\text{el}} = Q^{\frac{5}{2}} \frac{\sigma^{-3}}{\sqrt{2\pi}}; \quad P_{\text{hyp}} = \frac{1}{2} Q^2 (1 + \sigma^{-2}) - \frac{Q^{\frac{5}{2}}}{\sqrt{2\pi}\,\sigma^3}; \tag{51}$$

$$P = \frac{1}{2} Q^2 (1 + \sigma^{-2}).$$

Thus,

$$P_{\text{el}} = \frac{2}{\sqrt{2\pi}} \cdot \frac{\sqrt{Q}}{\sigma(1+\sigma^2)}; \quad P_{\text{hyp}} = 1 - \frac{2}{\sqrt{2\pi}} \cdot \frac{\sqrt{Q}}{\sigma(1+\sigma^2)}. \tag{52}$$

Since $\sqrt{Q}$ is of the order of $3 \cdot 10^{-3}$, while σ is of the order of 1, the probability of elliptical orbits proves to be low; consequently, the principle mass of the comet should have hyperbolic initial eccentricities if the comet comes from interplanetary space.

Only in the case when σ is of the order of $\sqrt{Q}$ (so that the problem is reduced to the Laplace distribution) can the probability of ellipses and hyperbolas be compared.

The fourth case can be reduced to the second on the basis of simple geometric concepts regarding the regions of the ellipses and hyperbolas of the hyperboloid of visibility. The conclusion is stated as follows: if $\bar{u}$, $\bar{v}$, $\bar{w}$ are not equal to zero and are finite values, then the probability of ellipses is practically equal to zero for any velocity distribution (even Laplace's type of distribution) relative to the velocity centrode.

Thus, considering the results of calculations relating to the most probable distribution of velocities, we must acknowledge (Schiaparelli) the inaccuracy of Laplace's cosmogony conclusions, and consider Fabry's conclusion on the formation of comets within the limits of the solar system to be the only correct one.

A statistical investigation of the directions of the axes of near parabolic comets (aphelion and perihelion directions) and calculations of the initial eccentricities of cometary orbits yield the same conclusions.

11. Statistics of Aphelion or Perihelion Directions /75

After the motion of the Sun relative to the stars was established with consistent certainty in the middle of the 19th century, this fact could be used in order to investigate the problem of comets. It is obvious that, if parabolic comets came from interstellar space, then the number of comets with aphelia in the region of the apex of motion of the Sun ($\alpha = 270°$, $\delta = 30°$) should greatly exceed the number of comets coming from other directions because of the movement of the solar system. Carrington was the first to attempt to find the predominance of aphelia of cometary orbits in the hemisphere containing the apex of the solar motion, but he obtained a negative result.

A. Sverdstrup was the next to work in the field of the statistics of directions of the semiaxes of cometary orbits. He looked for the positions of the poles of circles with maximum concentration of perihelion directions of near parabolic comets. In this case, it was stipulated that the sum of the squares of deviations from this minor circle of concentrations must be minimum.

Sverdstrup used 207 almost parabolic orbits ($e > 0.995$) and found the following ecliptical coordinates of the pole of the circle of concentrations: $\lambda = 178.4°$, $\beta = 29.4°$; the coordinates of the poles of the circles of divergence: $\lambda_1 = 84.0°$, $\beta_1 = 7.6°$; $\lambda_2 = 160.9°$; $\beta_2 = -59.4°$. The first pole was found to coincide closely with the pole of the Milky Way. Thus, it began to be considered that Sverdstrup's study indirectly confirmed the theory of the interstellar origin of comets, although it is obvious that the absence of any indications in the distribution of perihelia for the movement of the Sun in space speaks decisively against this conclusion.

Actually, the absence of effects of the motion of the Sun on

the distribution of aphelia of comets indicates that a comet swarm does not have preferential motion relative to the Sun and, consequently, accompanies it in space; however, this means that comets should arise in the solar system.

Results which were just as indefinite were obtained by Fabry, Janssen and Natanson. The latter used 345 comets and obtained an even more uniform distribution of aphelia in the sphere; the regions of concentrations were distinguished with much less definiteness, although the connection with the system of the Milky Way seemed to be preserved. The formal nature of the connection was emphasized by an investigation of Oppenheim, who found after studying the distribution of perihelia of cometary orbits that the principle direction of the distribution ellipsoid coincides with the direction of the pole of the Milky Way, while the other axis coincides with the direction of the vertex of stellar motions [21].

Even earlier, Eddington and Pickering pointed out that the /76
aphelia of comets are predominantly near ecliptical longitudes of $\lambda = 97^\circ$ ($\beta = \pm 16^\circ$) and $\lambda = 270^\circ$ ($\beta = -9^\circ$-70°).

As regards these results, it is important to mention that, according to Holetchek's conditions for visibility, the greatest concentration of perihelia should be anticipated at longitudes of 270 and 90°. For northern observers, the most advantageous periods for discoveries are the spring, summer, and autumn, which should lead to the predominance of comets with perihelion longitudes of about 270° ($q < 1$) or with longitudes of about 90° ($q > 1$). Only in the last few decades has the effect of seasonal conditions on comet discoveries decreased somewhat because of the increase of observatories and amateur astronomical studies both in the northern and the southern hemispheres.

Despite the absence of any effect of the motion of the Sun and the distribution of aphelion or perihelion directions, statistical investigations of cometary perihelia or aphelia have been continued.

In the 30's, thorough investigations of the ellipsoid of perihelion dispersion and the probability of comet discovery were carried out by the Belgian astronomers P. Bourgeois and J. Cox [22]. They obtained coordinates of $\lambda = 138.1^\circ$, $\beta = 86.4^\circ$ for the direction of the ellipsoid axis (which is the pole of the concentration of perihelia), which practically coincide with the poles of the ecliptic, and they found that two other axes had directions of $\lambda = 137.5^\circ$, $\beta = -3.6^\circ$ and $\lambda = 227.5^\circ$, $\beta = 0.0^\circ$.

This result was a direct invitation of a genetic relationship between comets and the solar system, and it showed the inaccuracy of the hypotheses of the interstellar origin.

After Holetchek, the problem of observational selection in discovery of comets was investigated by N.D. Moiseyev [23], and

touched upon in calculations of Vsekhsvyatskiy, V.A. Dombrovskiy and T.V. Vodop'yanova. Different aspects of the problem were treated here.

In 1935, P. Bourgeois and J. Cox attempted to find the probability of a discovery, depending on the brightness of the comet, by studying the distribution of the orbits of 417 long-period and near parabolic comets. They considered the probability of a discovery to be proportional to the time interval during which the comets had apparent brightness more than sufficient for a discovery. The corresponding calculations were carried out for parabolic orbits with values of q of 0.2, 0.6, 1.0, 1.5, 2.0 and 3.0. The values found for the probabilities did not show anything similar to the effect of the motion of the solar system, although the authors also attempted to link the ellipsoid axes they found with the plane of the galaxy or with direction of 90° from the center of the Galaxy.

Indefinite results were also obtained by O. Schmidt who examined 383 orbits from the Yamamoto catalogue (1945) and attempted to prove that in the present state of motion in the cometary complex, the initial conditions are affected when the diffuse material, from /77
which planets are formed, was captured during passage through the galactic plane [65].

Despite the negative results of the cited studies, the statistics of the perihelion directions of cometary orbits have very recently drawn the attention of researchers.

In 1965, Professor J. Witkowski [24], referring to a study by Khurnik (1964), examined the distribution of the perihelia of the orbits of 301 comets (with periods longer than 31,000 years) and concluded that there can be two comet streams with apexes of motion of $\alpha = 80°$, $\delta = 17°$ and $\alpha = 258°$, $\delta = -49°$; i.e., almost directly opposite in direction. Khurnik and Witkowski even estimated the position of the apex of solar motion relative to the complex of comets; however, they obtained directly opposite results.

If we recall that the near parabolic comets should have been characterized at the boundary of the solar system by relative velocities in the range of 0 ± 0.1 km/sec, and that the suggested comet streams could not have a connection with the interstellar regions, for which velocities of tens of kilometers per second are characteristic, then the invalidity of these ideas becomes completely obvious. Therefore, we must acknowledge that the statistics of comet directions which do not undergo the effects of the solar motion should serve only in characterizing a system of comets as in important components of the bodies of the solar system.

Hoping to see signs of galactic effect in the results of the comet statistics (in that the maximum concentration of perihelia corresponds to the region of the Milky Way), although these results become more and more indefinite as the number of comets included

in these statistics increases, the authors do not give any explanations of this "galactic" effect for some reason. Are they not assuming that the contribution to the system of comets comes primarily from the objects of the plane component of the Galaxy, and that these interstellar ice fragments pass "unnoticed" through a local system of stars, so as to converge with the Sun, moving from different directions at a relative velocity no higher than 100-150 m/sec? The authors also do not consider the idea that the hardly noticeable "galactic" effect could be the simple consequence of an insufficient number of objects included in the statistics. Finally, as seen in the distributions of the inclinations in Figure 4, near parabolic comets show substantial deviations from a uniform distribution; these distributions may be attributed with sufficient reliability to the effect of disturbances from neighboring stars on the external components of the system of comets.

The question which Fesenkov formulated on the effect of stars /78
on the motion of near parabolic comets was examined by J. Oort in connection with his hypothesis of a "cometary cloud" surrounding the solar system. We will discuss some aspects of this hypothesis later, but we will now examine the problem of the frequency of convergences of the solar system with stars.

Let d signify the density of the stars in the neighborhood of the Sun (according to Oort, $d = 3 \cdot 10^{-57}$ stars/cm^3). If $\bar{v}$ is the average relative velocity of the stars (cm/sec), R is the distance within which convergences of the stars can be expected (cm), then the probability that a star will be inside the target area (πR^2) in a unit time is proportional to $\pi R^2 d\bar{v}$.

The time interval between two successive passages of stars at a distance less than R is then equal to the following:

$$T = \frac{1}{\pi R^2 d\bar{v}} \text{(sec) or } T = \frac{3{,}2 \cdot 10^{-8}}{\pi d\bar{v} R^2} \text{(years)}.$$

Table 2 gives values for average time intervals in which neighboring stars converge with the Sun.

TABLE 8

R, AU	T (years)
10,000	$2.4 \cdot 10^7$
30,000	$2.5 \cdot 10^6$
50,000	$1.08 \cdot 10^6$
100,000	$2.5 \cdot 10^5$
150,000	$1.1 \cdot 10^5$
200,000	$6.2 \cdot 10^4$

As can be seen from the table, passages of stars at the bound-

aries of the solar system (100-150 thousand AU) occur every 100,000 years; during the existence of a planetary system, such convergences should occur more than 10,000 times. During the same time, there should be hundreds of close approaches to distances less than 10,000 AU, which should have completely discouraged the ordered states (velocity no greater than 0.15 km/sec) implicitly assumed by the defenders of the interstellar hypothesis.

The semblance of a confirmation of this hypothesis by the conclusions from the statistics of the directions is based on the use of the word "galactic" ("galactic concentration") and on a formal transposition into the range of comets connected with these ideas of stellar astronomy. It is obvious that this formalism cannot withstand any criticism, and the problem thus formulated is a misunderstanding which was supported for a rather long period of time, despite the fact that it had long been resolved in connection with /79 the conclusions from the Laplace problem and the results of calculations of the initial orbit of hyperbolic and near parabolic comets.

In this regard, it is of interest to acquaint ourselves now with the problem of the Oort cloud of comets of which we spoke.

12. Oort's Hypothesis of a Cloud of Comets

In 1950, J. Oort [25] independently concluded on the basis of the distribution of values of $1/a$ for the most precisely determined orbits of near parabolic comets, as well as the negative results of the statistics on perihelion directions, that the comets always belonged to the solar system. As is clearly shown by Van Woerkom (1948), the disturbing effects of planets, mainly of Jupiter, should bring about the ejection of near parabolic comets from the solar system. One or two million years after the first perihelion passage, the near parabolic comet should acquire hyperbolic eccentricity and should move out of the solar system, or it should become periodic, leaving the region of parabolas, as a result of the accumulative effect of small disturbances.

According to Oort, the cloud of comets should extend up to 150,000 AU.

The steady motion in the comet cloud, where the comets which are far removed from the Sun can preserve reserves of ice ("cometary icebox"),is disturbed, according to Oort, by perturbations from stars.

Oort examined the average effect of stellar passage on the change in velocities of comets in the cloud, and showed that the greater number of comets acquire velocities at the boundary of the cloud which exceed the escape velocities in a time on the order of $3 \cdot 10^9$ years. Thus, the stellar perturbations limit the dimensions of the cloud of comets. The inner boundary of the cloud is determined by the effect of planetary perturbations, which should carry

comets with $a < 10{,}000$ AU out of the solar system in a time of about 10^6 years.[13] Having examined the nature of movements in the cometary cloud, Oort concluded that, during the time the solar system has existed, all the preferential motions (for example, according to the radial direction toward the Sun or with respect to the ecliptic) are smoothed out by stellar perturbations, which introduce velocities of the same order on different coordinates. /80

For the calculations, there is a model where the directions are assumed to be equally uniform and the distribution of velocities of the comets in the cloud is such that the average velocity is comparable to the parabolic velocity for the given region. However, Oort rejects the Maxwellian velocity distribution, since the density of comets at short distances should then be very great, which does not agree with the distribution of semiaxes of the cometary orbits. Instead of this distribution, the one considered the most probable from the point of view of the laws of coincidence is a rather artificial form of the distribution by which there are no velocities equal to or greater than escape velocity.

Furthermore, Oort examined comets with near radial velocity directions with respect to the Sun, and he estimates the conditions for the change in directions resulting from stellar disturbances qualitatively. It is considered that, with this mechanism, the "new" comets which had been in the cloud are introduced into the visibility range and become known to terrestrial observers.

As Van Woerkom showed, their subsequent fate is that, with probability equal to 1/2, they will either acquire a hyperbolic nature of motion by the effect of planetary disturbances, or their orbits will be largely preserved and they will become stable periodic members of the system of comets, passing into the ranks of "old" comets after a few revolutions.

Using his velocity distribution function, Oort estimates the relative number of comets introduced into the visibility range from different regions of the cloud, and he determined the average density of the comets at a distance on the order of 50,000 AU. This density is equal to $6 \cdot 10^{-5}$ comets/1 AU^3. In this case, the total number of comets in the cloud is found to be in the order of $2 \cdot 10^{11}$, while Oort assumes their total mass to be equal to 1/10 of the mass of the Earth.

An examination of the theoretical and observed distributions of the values of $1/a$ near the parabolic limits shows that they do not agree. Almost 5 times more comets are found near the parabolic

[13] After calculating the disturbances from the nucleus of the galaxy directly, G.A. Chebotarev recently showed that the consistent motion is possible only up to a distance of 80,000 AU, and that the boundaries of the "cloud" should be on the order of 60,000 - 100,000 AU.

limit from the observed distribution than follow from the calculations. The conditions for selection of the materials also has a great effect here, since only comets with reliably determined orbits are included here; i.e., absolutely bright comets which could be observed during a long period of time, with advantageous division of the orbits relative to the Earth and Sun. All of this shows how the position of comets into "new" and "old", the criteria for which Oort suggests is a value of $1/a$ is hardly probable. Oort and Schmidt attempted to find the physical differences in comets of the different types, but without any success. This is completely understandable if we consider the determinate value of the conditions of observational selection for the comets used. On the other hand, it is obvious that it is absolutely unnecessary to assume complete physical identicalness of all the comets remaining in the cloud, as done implicitly by Oort. Actually, we know of substantial differences in the structure of cometary nuclei, in the chemism of their ice, in the quantity of meteoric matter (very fine cosmic dust), etc. /81

The principal reproach regarding this interesting theoretical examination by Oort could be made in connection with the arbitrariness and artificialness of his functions of the distribution of velocities in the comet cloud. The directions of the velocities are assumed to be equally probable, but the values for velocities are considered to be grouped around the parabolic velocity for the given distance, so that the hyperbolic velocities are considered to be absent. Oort used the following type of velocity distribution functions: $f(V) = 3\frac{V^2}{L^3}$, when $V < L$ and L is some constant value which is less than the escape velocity for the given distance. Considering this assumption, the value of L at a distance of 150,000 AU is found to be in the order of 54 m/sec, while that at a distance of 25,000 AU is about 250 m/sec.

Oort repeats the assumption which Laplace used and, naturally, obtained the desired result. However, the following question is raised: could there be no hyperbolic velocities directed toward the Sun in the cloud? In due time, Vsekhsvyatskiy showed that, as a result of repeated passages of stars, hyperbolic velocities should appear in a significant quantity in the cloud for those comets which, according to Oort's idea, are directed toward the Sun from the "cometary icebox".

Naturally, we should be interested primarily in the hyperbolic velocities directed toward the Sun [38].

For steady motion of comets in the cloud, their velocities should be close to spherical for the corresponding distances (since $V = \frac{3 \cdot 10^4}{\sqrt{R}}$ m/sec, then for R = 100,000 AU, $V \approx 100$ m/sec, while for R = 10,000 AU, $V \approx 30$ m/sec); therefore, during the passage of stars in the region of the cloud, the velocity of the comets relative to

a star is practically the same as that of the star relative to the Sun. The change in energy of the comets or inverse value of the semiaxis of its orbit relative to the Sun can be estimated approximatively by using the expression of H. Newton:

$$\frac{1}{a_{\cdot}} - \frac{1}{a_{in}} = \frac{4M \cos\varphi \sin\alpha}{PS}, \qquad (53)$$

where a_{in} is the initial semiaxis of the cometary orbits, M is the mass of the star, expressed in percentages of the solar mass; P is a value approximately equal to the parameter of the cometary orbit relative to the star; S is the ratio between the velocity of the comet relative to the star and the velocity of the star relative to the Sun; 2α is the angle between the asymptotes of the hyperbolic orbit of the comet relative to the star, ϕ is the angle between the direction of the velocity of the star and that of the periastron of the cometary orbit relative to the star. /82

In order to estimate the order of magnitude of $\Delta\frac{1}{a}$, we should mention that M should generally be close to 1; P may vary from 0 to the dimensions of the cloud (i.e., 10-100 thousand AU); S, according to the initial conditions assumed in the cloud, is close to unity; $\sin\alpha$, if we consider the stellar velocities, is also close to 1 and is always > 0. The value of a_{in} is on the order of R and $a_{in} > \frac{R}{2}$.

Thus, the sign of $\Delta\frac{1}{a}$ is determined by the sign of $\cos\phi$, while the value of $\Delta\frac{1}{a}$ depends mainly on the values of $P = A\ (E^2 - 1)$, which is less than or much less than $R(P << R)$.

It follows from the conditions for convergence of a star with the comet cloud (which actually can be considered as a star running against almost fixed particles of the cloud) that ϕ is always greater than 90°; i.e., $\cos\phi < 0$. Actually, in the case when the velocity of the star is 2 orders higher than the relative velocities in the cloud, the relative orbits are abrupt hyperbolas and $\cos\phi = -\frac{1}{E}$.

Thus, for the actual conditions in the neighborhood of the solar system, $\Delta\frac{1}{a}$ is always negative and frequently exceeds $\frac{1}{a_{in}}$ in magnitude, i.e.,

$$\frac{1}{a_{in}} \ll \left|\Delta\frac{1}{a}\right|.$$

Therefore, as a result of repeated passages of stars through the region of the Oort cloud, the majority of the comets should acquire substantial hyperbolic velocities and the velocity distribution will not correspond to the form suggested by Oort.

It is well known that it is almost impossible to observe objects with hyperbolic initial orbits from among the comets. Because of the stellar passages, the result of the perturbations from the nucleus of the Galaxy, the cloud of comets itself should have dissipated rapidly into interstellar space in a time no greater than order of magnitude of 10^8 years; tens of passages should occur during this time at distances of 10-20 thousand AU, and thousands of stellar passages should occur in this time near the boundary of the effective sphere of the Sun.

We must mention that the magnitude of the effective sphere of the Sun in the gravitation field of the nucleus of the initial Galaxy proved to be of the order of 60,000 AU, which excludes the possibility of extending the cloud of comets to distances of 200, /83
000-150,000 AU.

All of these facts indicate that Oort's steady cloud of comets really does not exist. At the same time, these conclusions do not negate the possibility of the formation of different groups of small bodies as the result of the disruption of a planet which Oort suggested in order to explain the origination of the comets and the cloud of comets. We will see later that there are many indications that meteors and other groups were formed as the result of high-energy eruptive processes on different planetary bodies. As will be shown, these ideas are being affirmed by studies of different problems of the solar system.

However, Oort postulated the disruption of a planet and the formation of the cloud of comets during the initial period in which the solar system existed, or about $3 \cdot 10^9$ years ago.

In order to explain the number of parabolic comets presently observed (or the total number of comets in the cloud), we calculated the total number of comets appearing in the disruption of the planet. It was found that this total number of comets with combined mass greater than 10^{30} g should have exceeded 10^{15}. It was difficult to assume that one of the planets had a mass comparable to that of Jupiter, and was divided into parts, while other planets, according to Oort's idea, did not take part in the origination of comets and other small bodies.

According to Van Woerkom, short-period cometary orbits arise as the result of perturbations from planets which "capture" individual objects from the field of near parabolic comets; therefore, they should not be considered when solving the problem of the origin of comets. However, it was the problem of the short-period comets which was the first step toward an explanation of the actual evolution of comets and other groups of small bodies.

13. Short-Period Comets; the Capture Problem

After the first short-period Comet Lexell was discovered, and

after the determination of the short-period nature in movement of Comets Helfenzrider, Pigott, Grishov, Encke, Tuttle and other comets, researchers began to study in detail the problem of large disturbances, the problem of capture formulated to Laplace when two periodic comets were known: Halley and Lexell.

In Volume IV of Laplace's "Course in Celestial Mechanics", this author examined the problem of large disturbances and wrote down the results of the calculations of Burkhardt concerning comet Lexell and other short-period comets. However, Laplace never formulated his positions concerning the fact that all the short-period comets arose as the result of transformations of the primary extended orbit by the effect of strong planetary disturbances. The capture problem was formulated later by the followers of Laplace, among /84 which, after Burkhardt, we should mention Le Verrier, H. Newton, Tisserand, and Callandro. Thus, we owe the formulation of the problem and the principal results of the "capture theory" to French theoreticians.

Let us examine the essence of the problem in brief.

Laplace introduced the term of the "effective sphere" of the planet, and showed that an estimate of the large disturbances can be obtained if the parameters of motion at the boundary of the effective spheres are established, if the planetocentric relative orbit is found, and if we again convert to heliocentric motion when the comet moves out of the effective sphere. The condition for determining the effective sphere of a planet (or a small body in the field of gravity of another body, in general) can be obtained by considering that the ratio between the principle force and the disturbing one should be equal in both cases: when body A (for example, the Sun) is considered to be central, while B is disturbing or when body B is acknowledged as the central one.

If F characterizes the effect of the Sun on the comet, while R is the disturbing force from the planets, then

$$\frac{R}{F}=\frac{R_1}{F_1}, \tag{54}$$

where R_1 is the disturbing force of the Sun, while F_1 is the attraction of the comet to the planet.

Calling the mass of the Sun M, the mass of the planet m_1, and the distances to the comet from the Sun and from the planet r and ρ, respectively, we obtain the following (assuming that all three bodies are on one straight line):

$$F=\frac{fM}{r^2};\quad F_1=\frac{fm_1}{\rho^2},$$

so that

$$R = fm_1\left[\frac{1}{\rho^2} - \frac{1}{(r \pm \rho)^2}\right]; \quad R_1 = fM\left[\frac{1}{r^2} - \frac{1}{(r \pm \rho)^2}\right]. \tag{55}$$

Assuming ρ to be a small value compared to r, we may use the following:

$$R \approx \frac{fm_1}{\rho^2} \text{ and } R_1 \approx fM\left(\frac{2\rho}{r^3}\right). \tag{56}$$

Then, using (54), we find that

$$\rho = r_1 \sqrt[5]{\frac{1}{2} \cdot \frac{m_1^2}{M^2}}. \tag{57}$$

For the general case,

$$\rho = r_1 \sqrt[5]{\left(\frac{m_1}{M}\right)^2 \cdot \frac{1}{\sqrt{1 + 3\cos^2\varphi}}} = \\ = r_1\left(\frac{m_1}{M}\right)^{\frac{2}{5}}(1 + 3\cos^2\varphi)^{-0.4} \tag{58}$$

(here ϕ is the angle between the direction toward the Sun and the point on the surface of the "effective sphere"). /85

The radii of the effective sphere of planets and some satellites are given in Table 9.

TABLE 9

Planet	ρ, AU	Satellite	ρ_p, AU
Mercury	0.001	Moon	0.00044
Venus	0.004	Io	0.00005
Earth	0.006	Europa	0.00007
Jupiter	0.322	Ganymede	0.00017
Saturn	0.366	Callisto	0.00024
Uranus	0.339	Titan	0.00029
Neptune	0.576	Iapetus	0.00024
Pluto	0.241	Titania	0.00003
		Oberon	0.00004
		Triton	0.00017

The comet which is assumed to move along a parabolic orbit because of close convergence with a massive planet undergoes strong disturbances which change the shape of its original paths. The theory allows us to predict the nature of this change as a function of the conditions under which the comet entered the effective sphere

of the planet, i.e., as a function of the angle between the directions of motion of the comet and the planet, the ratio between their velocities and other characteristics of convergence.

The characteristics of the transformation of orbits are expressed in most compact forms in a relationship which has been called the Tisserand criterion, which is a particular case of the Jacobi invarient. We must discuss this study [26] in more detail, since the certainty that short-period comets of the Jupiter group arose and arise by capture was also connected with its effective results.

Tisserand first gives the following arguments: a comet reaches a planet (Jupiter) and enters into an effective sphere at point M_0 (Fig. 27); under these conditions, the angle of SJM_0 is close to $\frac{\pi}{2}$ and the velocity of the comet is directed approximately along M_0J. If the comet moves along a parabola, then its velocity at point M_0 is $v_0 = k\frac{2}{D}$, where D is the radius of the planet's orbit. The velocity of the planet, which is considered to move along a circle, /86 is $v_1 = k\frac{1}{D}$. The relative velocity of the comet can then be found:

$$V_0 = v_0 - v_1 = k\frac{\sqrt{2}-1}{\sqrt{D}}. \tag{59}$$

Under the conditions assumed, this velocity corresponds to the parameters of planetocentric motion:

$$V_0^2 = k^2 m_1\left(\frac{2}{\rho} - \frac{1}{A}\right), \tag{60}$$

where m_1 and ρ are the mass of the planets and the radius of its effective sphere, respectively, while A is the real semiaxis of the planetocentric orbit.

It follows from (59) and (60) that

$$\frac{1}{m_1}(\sqrt{2}-1)^2\frac{\rho}{D} = 2 - \frac{\rho}{A}. \tag{61}$$

For Jupiter, Tisserand found that A should be negative (this was obvious earlier). Since the hyperbola of the relative orbit is very extended, the comet, bending around the planet, moves out of the effective sphere near the input point at a velocity close to V_0, but directed to the opposite side. Then $V_1 = k\frac{1-\sqrt{2}}{D}$ and the heliocentric velocity of the comets while emerging from the effective sphere $v' = V_1 + v_1 = \frac{k(2-\sqrt{2})}{\sqrt{D}}$.

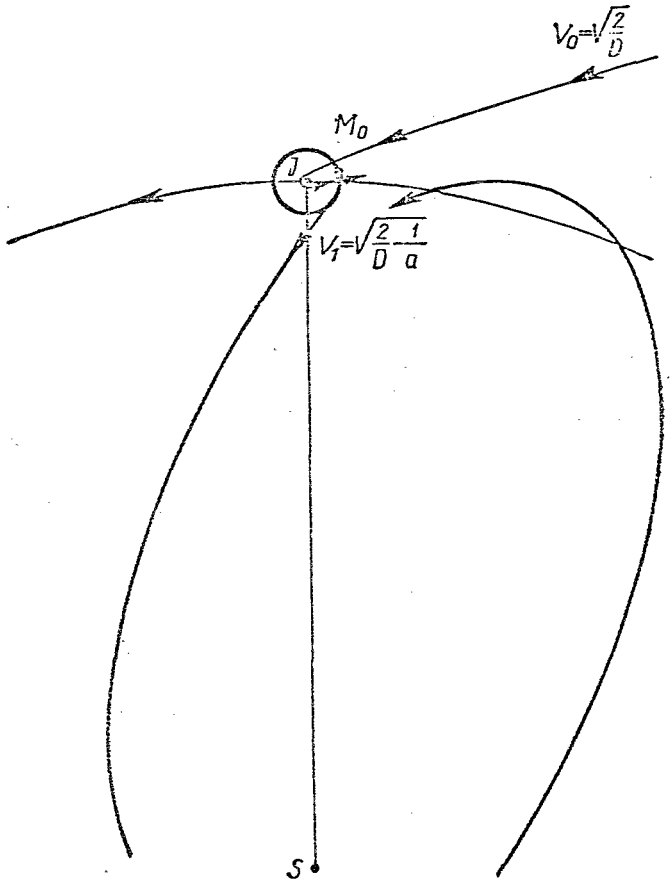


Fig. 27. Scheme of the Capture of a Short-Period Comet.

Since the position of the planet is considered to be altered insignificantly, the resultant velocity can be equated to the famous expression $\frac{k^2(2-\sqrt{2})^2}{D} = k^2\left(\frac{2}{D}-\frac{1}{a'}\right)$, so that $a' = D\,\frac{\sqrt{2}+1}{4}$ and for Jupiter (D = 5.2) a' = 3.14, i.e., corresponds precisely to the average value for the comets of the Jupiter group. This was a marvelous result in the true sense of the word. Although Tisserand mentioned that a completely opposing result could also be obtained when the initial elliptical orbit is converted into a parabolic or hyperbolic one, his effective calculations apparently served as a clear confirmation of the validity of the capture idea. /87

Examining the connection between the elements of heliocentric motion of a comet before and after conversions in a more general form, Tisserand obtained his celebrated relationship, which is called the "Tisserand Criterion":

$$\frac{1}{a_1}+\frac{2\sqrt{a_p}}{r_p^2}\cdot\sqrt{a_1\left(1-e_1^2\right)}\cos i_1 = \frac{1}{a_2}+\frac{2\sqrt{a_p}}{r_p^2}\cdot\sqrt{a_2\left(1-e_2^2\right)}\cos i_2 \qquad (62)$$

(it occurred in that case when the comet is disturbed by only one planet which has semiaxis of a_p and moves at the moment of convergence with the planet at a distance of r_p). This relationship is an invariant which connects the elements before the disturbance (subscript 1) to those after the disturbance (subscript 2). Thus, the development of the capture theory brought important theoretical results, which had to reenforce the ideas that the capture assumption correctly explains the characteristics observed in the system of short-period comets. /88

However, a deeper investigation showed that this was not true in reality. Tisserand and Callandro found the theoretical limit values to be the resultant eccentricities of comets appearing as the result of disturbances in original parabolic cometary orbits.

On the other hand, Gruille obtained a more general expression than Tisserand's relationship or Jacobi's integral, indicating that there were additional terms depending on the eccentricity of the orbit of the planets, the inclination of its plane to the ecliptic, etc.

Even before Tisserand, Clawson obtained some criteria to identify the elements of an orbit subjected to large disturbances.

In the general case, the limit eccentricity of an orbit converted from a parabola is found as the following:

$$e_{\min} = \sqrt{1 - \frac{D}{a}\left(\sqrt{2} - \frac{D}{2a}\right)^2}, \qquad (63)$$

where D is the radius of the planetary orbits, considered to be spherical; a is the resultant semiaxis. It is obvious here that the perihelion distance of the initial orbit should be less than D.

The ecentricities proved to be less than this limit $e_{\min}$ for a significant short-period comet . They include Comets Blanpain 1819 IV, De Vico-Swift, Tempel I, Tempel II, Barnard 1884 II, Brooks I 1886 IV, Spitaler 1890 VII, Brooks II, Grigg-Skjellerup, Holmes, Kopffs and Taylor 1916 I. The deviations from the theoretical limit value are particularly significant for more recent comets: this can be clearly seen from Table 10.

Thus, almost all the short-period comets prove to be more spherical, more similar in their motion to planets then is required by the capture theory. This absolutely opposes the idea of the formation of short-period comets by way of capture from a field of parabolic comets.

We saw earlier that the distribution of long-period and near parabolic comets over the values of the perihelion distance q gives a maximum in the vicinity of $q \approx 0.7$ AU, while the principal number

of comets (more than 70%) has q in the limits of 0.4-1.2 AU. For short-period comets, the maximum distribution is largely shifted toward higher q to values of 1.4-1.9 AU. Callandro showed that, for the captured comets, the values of q should decrease in the case of straight forward motion. This is one serious discrepancy between the conclusions of the capture theory and reality.

The next important fact is the absence of sharply hyperbolic orbits equivalent to those short-period orbits which are known in Jupiter's family of comets. At the same time Callandro and Tisserand noted that there must be the appearance of hyperbolas, considering that the reason why they could not be observed was either the significant resultant perihelion distance or the fact that, while moving out of the effective sphere, the comet was already departing from the Sun. We will see later that, in reality, a significant number of sharply hyperbolic orbits acceptable to observations should be formed. For that quantity of short-period comets which are presently known, we should have had several sharp hyperbolas. /89

TABLE 10

Comet	e	e_{min}
Neujmin II	0.57	0.65
Schorr 1918 II	0.47	0.52
Wolf 1924 IV	0.37	0.51
Schwassmann-Wachmann I	0.15	0.44
Schwassmann-Wachmann II	0.40	0.59
Whipple	0.35	0.51
Forbes	0.57	0.60
Reinmuth I	0.50	0.52
Kulin 1939 VIII	0.45	0.65
DuToit-Neujmin-Delport	0.59	0.68
Oterma	0.14	0.49
Du Toit II	0.59	0.68
Reinmuth II	0.47	0.58
Wirtanen	0.54	0.56
Ashbrook-Jackson	0.40	0.51
Johnson	0.38	0.56
Shayne-Shaldek	0.40	0.52
Harrington-Wilson	0.52	0.59
Harrington I	0.54	0.58
Harrington II	0.54	0.55
Su Chin Shan I	0.58	0.58
Su Chin Shan II	0.50	0.58

14. The Probability of Transformations of Orbits and the Theoretical Number of Comets with Different Periods

Even before the theoretical investigations by Tisserand and Callandro, the problem of capture and large transformations was

examined (in 1879) by the famous astronomer H.A. Newton, who constructed the geometrical picture for the phenomena and studied the problem of the probability of different types of orbits in the early 1890's.

Newton's principle relationship was an expression for the complete change in kinetic energy of a comet due to a convergence with a planet (Jupiter) at a distance less than the radius of its effective sphere (the effective radius can be taken as $\rho = 0.5$ AU for Jupiter). /90

Let ϕ_0 and ϕ_e be the angles of the planetocentric velocity of the comet with the direction of the planet at the entry and exit points on the boundary of the effective sphere; ϕ is the angle between the velocity of the planet and the direction of the periplanet relative to the orbit; v_0 and v_e are the heliocentric velocities of the comet before and after transformation (upon entry into the effective sphere and exit from it); r_0 and r_e are the corresponding distances of the comet from the Sun; w is the velocity of the planet in the heliocentric orbit, and D is the distance from the Sun to the planet. Since the planetary orbit is nearly spherical and ρ is small in comparison with D, when $V_0 \approx V_e$ (V_0 and V_e are the planetocentric velocities of the comet at the entry and exit points).

Considering the orbit of the planet should be spherical and that of the comet to be close to a parabola, we will find that $w^2 = \frac{k^2}{D}$; $v^2 = k^2 \left(\frac{2}{r} - \frac{1}{a}\right)$.

We find from the velocity parallelogram at the boundary of the effective sphere that

$$v_0^2 = V_0^2 + w^2 + 2V_0 w \cos\varphi_0,$$
$$v_e^2 = V_e^2 + w^2 + 2V_e w \cos\varphi_e, \qquad (64)$$

while, for the approximation used,

$$\frac{1}{2}\left(v_e^2 - v_0^2\right) = wV_0\left(\cos\varphi_e - \cos\varphi_0\right). \qquad (65)$$

Representing the directions of the periplanet and the entry and exit points on the planetocentric sphere, when the arcs between them are equal to $90° - \alpha$ and $90° + \alpha$ ($\alpha \approx \frac{\phi_e - \phi_0}{2}$), we find that $\cos\phi_e - \cos\phi_0 = -2 \sin\alpha \cos\phi$. Expressing the velocity in term of the constant of the areas in the relative orbits, we find the following:

$$\Delta\frac{1}{2}v^2 = -\frac{4k^2 m w}{P_0 V_0}\cos\varphi \sin\alpha. \qquad (66)$$

H.A. Newton formulates this conclusion in the following way [27].

The total increase in kinetic energy of the comets due to close conversion is proportional to the product of the momentum of the planet (mw) times the sine of one half the angle by which the direction of the comet changes relative to the planet ($\sin\alpha$), times the cosine of the angle in the planet between the velocity of the planet and the direction of the periplanet ($\cos\phi$) and is inversely proportional to the area constant in the relative cometary orbits ($\frac{P_0 V_0}{2}$).

Since $\Delta\frac{1}{2} v^2 = k^2(\frac{1}{a_e} - \frac{1}{a_0})$, then, using s instead of $\frac{w}{V}$ and the perpendicular from the planet to the asymptote of the relative orbits, P, instead of P_0, we obtain the following: /91

$$\Delta\frac{1}{a} = -4\frac{m\cos\varphi\sin\alpha}{Ps}. \tag{67}$$

we then can find the expression for the resultant semiaxis (if the initial orbit is a parabola):

$$a = \frac{Ps}{4m\cos\varphi\sin\alpha}. \tag{68}$$

The sign of the semiaxis (i.e., the nature of the transformation) depends only on the sign of $\cos\phi$, since all the remaining values are always positive. If $\phi < \frac{\pi}{2}$ (the periplanet in front of the planet), then $a > 0$ and the formation of a periodic orbit occurs. For $\phi > \frac{\pi}{2}$, i.e., when the periplanet is behind the planet in its motion, then the energy in movement of the comet increases and its orbit should convert from a parabola to a hyperbola. Newton expressed this important position in the following theorem: when a comet passes in front of a planet, it's kinetic energy decreases, while if it is behind, then the kinetic energy increases.

If ω denotes the angle between the heliocentric velocity of the comet and the velocity of the planet at the point of greatest convergence, then

$$V_0^2 = w^2 + v^2 - 2wv\cos\omega$$

and

$$s^2 = 1 + \left(\frac{2}{D} - \frac{1}{a}\right)D - 2\sqrt{\frac{2}{D} - \frac{1}{a}}\cdot\sqrt{D}\cos\omega. \tag{69}$$

Expression (69) has the following form for an initial parabolic orbit:

$$s^2 = 3 - 2\sqrt{2}\cos\omega. \qquad (70)$$

Newton calculated the conditions for convergence of comets with Jupiter for the assumption in (70). Table 11 shows values of s and A for different values of ω (A is the real semiaxis of the relative orbit), as well as values of h', h'', a' and a''. (The values of h' and h'' are expressed in astronomical units of the distance to Jupiter from the point of intersection between the orbit of the comet and the planets at the time when the comet passes through this point; h' corresponds to cases when the comet passes in front of the planet, and h'' corresponds to passage behind the planet; a' and a'' are resultant semiaxis of the heliocentric orbits.)

TABLE 11

/92

ω	s	A	h'	h''	a'	a''
0	0,414	0,02886	0,01443	∞	3,14	∞
5	0,427	0,02716	0,01388	—0,63915	3,11	—144,0
10	0,463	0,02309	0,01250	—0,15174	3,04	—36,94
15	0,518	0,01848	0,01082	—0,06302	2,94	—17,13
20	0,585	0,01448	0,00970	—0,003307	2,85	—10,15
25	0,660	0,01136	0,00795	—0,001987	2,76	—6,86
30	0,742	0,00900	0,00690	—0,001290	2,69	—5,03
35	0,826	0,00725	0,00609	—0,00896	2,64	—3,89
40	0,913	0,00594	0,00545	—0,00654	2,61	—3,13
45	1,000	0,00495	0,00495	—0,00495	2,60	—2,60
50	1,087	0,00419	0,00457	—0,00387	2,61	—2,21
55	1,174	0,00360	0,00427	—0,00310	2,63	—1,91
60	1,259	0,00312	0,00407	—0,00253	2,69	—1,68
65	1,344	0,00275	0,00392	—0,00211	2,77	—1,49
70	1,426	0,00244	0,00382	—0,00179	2,86	—1,34
75	1,506	0,00218	0,00377	—0,00154	2,98	—1,21
80	1,584	0,00197	0,00377	—0,00134	3,14	—1,11
85	1,660	0,00180	0,00381	—0,00119	3,32	—1,03
90	1,732	0,00165	0,00390	—0,00105	3,55	—0,95
95	1,802	0,00153	0,00405	—0,00094	3,86	—0,80
100	1,868	0,00142	0,00426	—0,00085	4,17	—0,83
105	1,932	0,00133	0,00453	—0,00078	4,60	—0,29
110	1,992	9,00125	0,00489	—0,00072	5,12	—0,75
115	2,048	0,00118	0,00534	—0,00066	5,77	—0,71
120	2,101	0,00112	0,00598	—0,00062	6,60	—0,68
125	2,150	0,00107	0,00680	—0,00658	7,67	—0,66
130	2,195	0,00103	0,00789	—0,00055	9,09	—0,63
135	2,237	0,00099	0,00939	—0,00052	11,03	—0,61
140	2,273	0,00096	0,001149	—0,00050	13,71	—0,60
145	2,305	0,00093	0,001157	—0,00048	17,67	—0,58
150	2,334	0,00091	0,001934	—0,00047	23,70	—0,57
155	2,359	0,00088	0,002731	—0,00045	33,82	—0,56
160	2,379	0,00087	0,004192	—0,00044	52,36	—0,55
165	2,394	0,00087	0,007259	—0,00043	91,26	—0,55
170	2,405	0,00086	0,016339	—0,00043	206,30	—0,55
175	2,412	0,00085	0,061430	—0,00043	778,0	—0,54
180	2,414	0,00085		—0,00043		—0,54

The data of the table clearly show what conditions there should be for convergence at initial parabolic velocity of the comet, in dependence on the angle between the directions of the velocities,

so that the planet has maximum effect on the comet during the entire time in which the comet is in its vicinity.

For example, if the angle between the velocity directions is $\omega = 75°$, then Jupiter has greatest effect on the comet (in a decreasing momentum) in that case when the planet is at a distance of $h' = 0.00377$ AU behind the comet; in this case, the resultant semiaxis is $a' = 2.98$. If the comet passes behind the planet at the same angle $\omega = 75°$, then the greatest effect is at $h'' = -0.00154$ AU (Jupiter is in front of the comet); as a result, the parabolic orbit converts into a sharp hyperbola with $a'' = -1.11$. /93

The number of transformed hyperbolic comets for the case under investigation should be somewhat greater than the number of corresponding periodic and short-period comets, in view of the fact that the number of comets encountered, for arbitrary distribution of the directions of initial velocities, is greater than the number of overtaking comets. Nevertheless, no single comet with abrupt hyperbolic eccentricity corresponding to the equivalent short-period (e = 2-6 AU), has been observed during the entire history of astronomy. Callandro attempted to explain the absence of hyperbolas in terms of the fact that many comets (about one half) are directed away from the Sun after convergence with their planets, while others obtain greater perihelion distances. However, it was found that a substantial number of comets should be directed toward the Sun and should be incident in the visibility range (q < 2-3 AU). In order to rescue their position, the defenders of the capture hypothesis set forth the idea that the transformation occurs not only with parabolic comets, but that a large number of comets can move in the region of Jupiter with all possible types of orbits, of the way to spherical ones similar to planetary orbits. Nevertheless, no one examined this problem theoretically.

We have already seen that there is no equilibrium state in the system of comets, and that this should have occurred if the nature of cometary orbits were determined solely by the effect of planetary perturbations and if the comets were physically stable bodies. Let us see whether or not the modern state of the system of comets can be explained on the basis of the expansion pattern proposed by Laplace.

We will assume that the comets move in the region of Jupiter's orbit at velocities from 0 to $\sqrt{\frac{1}{D}}$, i.e., at velocities which are low compared to that of the planets; in this case, only head-on comets with $\phi > 90°$ will be incident in the effective sphere.

In all cases, there will be an increase in the energy of the comets and, for rather close convergences, the formation of sharply hyperbolic orbits. Many of them should be incident in the visibility range.

Another possibility is that the initial comets have almost spherical and elliptical orbits; at a distance of D the velocities are distributed uniformly near a value of $\sqrt{\frac{1}{D}}$; all the comets have straight forward motion. It is obvious that, in this case, an approximately equal number of head-on ($v < \frac{1}{\sqrt{D}}$) and overtaking ($v > \frac{1}{\sqrt{D}}$) comets will converge with the planets. The former will convert into comets with long-period and hyperbolic orbits. Among the second, there must necessarily be some number of periodic orbits with short periods, but with retrograde motion. The absence of hyperbolic orbits, which should have appeared considering the high frequency of equivalent short-period comets, is a strong argument against the capture theory. An even weightier argument against the capture theory is the absence of short-period comets with retrograde motion. /94

Thus, the nature of the orbits of all the short-period comets we know contradicts the capture theory. Let us now find what can be seen in the absolute value for the probability of close convergence.

In studying the possibility of collisions between comets and the Earth, Olbers raised the question of the probability of convergences of a comet with a planet at a distance less than ρ, and he determined this probability by the following ratio: $W = \frac{\rho^2}{D^2}$ (D is the distance to the planet from the Sun).

Taking ρ as the values for the radii of the effective sphere, we find the following probabilities for different planets: Mercury -0.000007, Venus -0.000031, Earth -0.000036, Mars -0.000007, Jupiter -0.003832, Saturn -0.001448, Uranus -0.000313, Neptune +0.000367.

Even for Jupiter it is found that, of one thousand comets passing inside a sphere with radius with 5.2 AU, only four can converge with the planets at a distance less than the radius of its effective sphere, i.e., 0.32 AU. The probability of transformation of a parabolic orbit into a short-period one is found to be even millions of times less.

H. Newton assumed that the number of comets in a unit volume remains constant regardless of the distance to the Sun, i.e., that the number of comets increases in proportion to q^3. It was also assumed that all the directions for cometary motions are equally probable at any point in space. These assumptions are very favorable to the capture idea and, despite their controversial nature, a calculation of the velocity of the comet and planet leads to almost the same expressions for the probability of convergence as that established by Olbers.

Examining the transformations of parabolic comets, H. Newton obtained the following expressions for the number of resultant cometary orbits with semiaxes less than a:

$$N = \frac{1}{4}\pi n m^2 v \int \left[4a^2 - \left(\frac{a - D - as^2}{s}\right)^2\right] ds, \tag{71}$$

where n is the number of comets per unit volume, m is the mass of the planets and v is the velocity of the comet.

Russell [28] showed later that, for the corresponding probability (proportional to the numbers of comets), the following expression is obtained: /95

$$W_a \approx \frac{4}{3} \cdot \frac{m^2 a^2}{D^2}. \tag{72}$$

After the corresponding complications, Newton found that, out of one billion comets passing through a sphere with radius of D = 5.2 AU, only 839 comets will move along short-period orbits with period less than the period of revolution of Jupiter (i.e., 11.8 years). Of these, only 644 will have straight forward motion and 195 will have retrograde motion. The theoretical distribution of resultant orbits over periods which is represented by the smooth curve in Figure 1 has nothing in common with the actual distribution. We do not know of one orbit with retrograde motion in Jupiter's system of comets, while the theory requires no less than 23% such comets. The theoretical distribution of inclinations for these comets also has nothing in common with the distribution observed. Out of the 839 comets, 54% will have i in the range from 0 to 60°, 31% from 60 to 120° and 15% from 120 to 180°. For 80 years, no one disputed Newton's results, although the most celebrated theoreticians of the time, for example Russell, analyzed them. Therefore, the probability must be estimated in a different way.

Let us start with Olber's expression for the probability for convergence of the comet with a planet at a distance less than ρ. Considering ρ to correspond in order of magnitude to the periplanetary distance, we can assume that $2\rho = \frac{P}{\sin\alpha}$ (P is the perpendicular from the center of the planet to the asymptote of the hyperbolic relative orbit, and α is 1/2 the angle between the asymptote).

Let us use Newton's expression $a = \frac{Ps}{4m\cos\phi\sin\alpha}$. For the quantity s, we will take its mean value, which is equal to $\sqrt{3}$, and we will consider that $\cos\phi$ determines only the sign of a; then $a \approx \frac{2\rho\sqrt{3}}{4m}$ and $\rho \approx \frac{2ma}{\sqrt{3}}$. Therefore, we find the following for the probability of transformation from a parabola of an orbit with semiaxis less than a:

$$W_a \approx \frac{4}{3} \cdot \frac{m^2 a^2}{D^2}. \qquad (73)$$

If the number of comets increases in proportion to the distance from the Sun, then the quantity of comets accessible to discovery and observations is equal to the following:

$$W_{1,a} \approx \frac{4}{3} \cdot \frac{m^2 \cdot a^2}{D^2} q. \qquad (74)$$

We have obtained an expression which coincides with Russell's formula (72). That is why, because the discrepancy between the value for the probability of transformation (on the order of 10^{-6}-10^{-7} for the comets of the Jupiter group) and the *a posteriori* probability of discovery (equal to 0.16-0.18 of the total quantity of new comets), it was suggested that the short-period comets are "attenuated", i.e., that they exist for a long period of time after capture. /96

The average number of mere parabolic comets discovered during one year is equal to 3. If Laplace and the theoreticians of the 19th century took a radius of the visibility sphere as 2 AU, it has now grown to 3-4 AU as a result of the expansion of sky surveying and the increase in effectiveness of observational media. Therefore, several tens of near parabolic comets should enter within the limits of a sphere of this radius every year. Multiplying this value by the probability of transformation, we can obtain the number of short-period comets (on the order of 10^{-5}-$10^{-4.5}$) which can appear during the course of one year according to the capture hypothesis. Consequently, the age of the short-period comet should be no less than tens of thousands of years and should average 10^5 years. More than 77 comets of the Jupiter family could "congregate" only in a time interval of the order of $7 \cdot 10^6$ years. Can short-period comets exist for such a long time?

Both a study of the secular changes in cometary orbits and in an investigation of the secular decrease in brightness of comets, or their disintegration, gives a definite answer to this question. For a comet moving along an orbit of the type of orbit in Jupiter's family, with aphelia near the orbit of the planets, the possibility of convergences with the planets and of large perturbutions of the orbits increased to a large extent. We have seen that there should be an increase in energy of the comets sooner or later in this case, and it will leave the solar system or, directed toward the Sun, will fall on its surface. K. Schwarzschild examined the problem of the stability in motion of a captured comet in 1895: he showed that the "captured" comet should leave the region of Jupiter's comets. This general theoretical conclusion is also confirmed by a calculation of the motion of several conditional asteroids and comets [39], which

undergo great changes in a time interval of hundreds or thousands of years, and which leaves the original range of motion.

The results of an investigation of the absolute magnitudes of many short-period and periodic comets proved to be even more determinate.

15. Absolute Magnitudes and Disintegration of Short-Period and Periodic Comets

In his first study investigating the law for the change in brightness for comets and determining their absolute magnitudes, Vsekhsvyatskiy [30] detected a systematic variation in the average value of absolute magnitudes as a function of the semiaxis of the orbits and the inclination of the orbits. Values of $\overline{H}_{ab}$ were obtained on the basis of Holechek's values, reduced to the new law ($y = 10$), and H_B were determined for comets of 1883-1921 on the basis of new data (see Table 12). /97

TABLE 12

Range of a	No. of Comets	$\overline{H}_{av}$	No. of Comets	$\overline{H}_B$	i^0	No. of Comets	$\overline{H}_{av}$	No. of Comets	$\overline{H}_B$
3—10	8	7,8	15	9,5	0—20	28	6,9	16	8,6
10—100	14	5,3	5	7,9	20—40	36	6,5	20	7,5
100—1000	18	4,5	34	6,9	40—60	49	5,8	10	7,0
1000	140	5,8			60—90	67	4,9	8	7,1

This variation in absolute magnitudes was then explained by the assumption that comets which have small a and i disintegrate very rapidly.

In 1927, after studying estimates of the brightness of Comet Encke during different appearances, the author detected a systematic decrease in the brightness of the comet by no less than 1^m per century. In 1929, the American astronomer N.F. Bobrofnikoff studied data which characterized the brightness of almost the same 180 comets, and he affirmed the correlations shown in Table 12. He assumed that there was simultaneous formation of all the comets and a constant rate of disintegration, and he found correlations between the disintegration function of the comets and their absolute magnitudes.

In 1930, Vsekhsvyatskiy determined and investigated the absolute magnitudes of 13 more short-period comets in different appearances, and he found a rapid and indisputable diminution (disintegration) of the comets in a number of cases. Maximum values of ΔH (decrease in brightness in stellar magnitudes in 1/2 a century) were obtained for Comets Faye, Finlay, Wolf, Brooks II and Kopff.

It was found from a comparison of these data with the dissipation function $\Phi = 2 \log a + \log (1 - e^2)$, which characterizes the

conditions of the solar effect, with the position relative to the solar equator and with a number of other factors, that the comets under investigation could be divided reliably into groups before 1880 ("old") and after 1880 ("young"), while the average value of $\Delta H = 1.2^m$ for the "old" comets, while it is 3.8^m for the "young" ones.

The high speed of distegration shows that the comets were young and that they were formed recently within the limits of the solar system. A significant number of comets which had disappeared which were observed during 1 appearance was also noted. This could be the result of rapid disintegration for some of them.

If we consider the rate of loss in absolute brightness to be constant, we can estimate the maximum permissible "photometric" age of the comet [31] as $A_e = 50 \frac{H_{1900} - H_{in}}{\Delta H}$, where H_{in} cannot be less /98 than -1^m, which corresponds to the absolute magnitude of the brightest of the known comets.

As a result of the subsequent observations and more precise determinations of the values of ΔH, values corresponding to several tens and, at the most, several hundreds or thousands of years were obtained for the limit age of comets.

The conclusions on the rapid disintegration of comets were criticized by Bobrofnikoff (1942). Using the example of Comet Wolf, Bobrofnikoff attempted to show that there were large systematic errors in photometric observations and that the theories on the rapid disintegration of comets were not convincing. Vsekhsvyatskiy (1950) showed that discrepancies in the reduction methods which Bobrofnikoff used, as well as his conclusions, and he confirmed that there was a rapid decrease in this comet. The rapid disintegration of Comet Wolf was corroborated independently by the famous Polish astronomer M. Kamenskiy, the founder of the theory of motion of this comet.

A detailed analysis of observations of Comets Faye, Brooks II and Brorsen and a recalculation of the secular change in their brightness were carried out in 1951-1952 by V.I. Cherednichenko and V.P. Konopleva. These investigations confirmed Vsekhavystskiy's results in full.

The problem of the sharp change in absolute brightness of comets was investigated most thoroughly by Z. Sekanina [32], who reviewed a large amount of the data of photometric observations in the monograph by Vsekhsvyatskiy entitled "The Physical Characteristics of Comets". Sekanina's curves for the decrease in absolute brightness of 17 comets, most of which were observed in more than 5 appearances, are given in Figure 28.

The depletion of Comets Faye, Wolf I, Brooks II and Grigg-Skjellerup occurred most rapidly. All the other short-period and periodic comets also lose reserves of "ices" of hydrocarbon compounds, sometimes showing great oscillations in the values of H_{10} from 1 appearance to another. These variations can be explained by the systematic deviations in the estimates and measurements of the brightness in different appearances (different observers and instruments, difference in the conditions for observations of the comets, lack of the requisite number of observations). An investigation of the observations in the 19th century and many of the observations during the last decades shows that this source of errors cannot exceed $0.2\text{-}0.3^m$ for the absolute magnitude of a comet of average brightness. The oscillations on the curve for the secular variations in absolute brightness can be caused more often by the effect of the level of solar activity, which is also certainly seen on the curve for comet Encke and in many other cases.

Whipple recently examined the problem of disintegration of 9 comets, and he repeated Vsekhsvyatskiy's earlier prediction that some of these comets would soon disappear from our present range of observational potentials [33].

Despite the numerous cases of a sharp diminution of comets, and despite the definite statistical criteria presented by Sekanina, we continue to find some articles which cast doubts on these conclusions concerning the rapid disintegration of comets. Examining the data of Comets Encke, L. Kresak (1965) came to Bobrofnikoff's conclusion of 1942-1943 concerning the seeming understatement of estimates of the integral brightness of comets at present compared to the first observations of short-period comets of the 18th and 19th centuries, and containing a very slow photometric evolution of the comets. Obviously, Kresak was not acquainted with the thorough investigations by Cherednichenko and Konopleva[14], in which all the observations carried out during the first and most recent appearances were analyzed, and a unit system of estimates was developed. This very principle of a unit system was supported in an analysis of a very large amount of observational materials discussed in the monograph entitled "The Physical Characteristics of Comets"[15]. Therefore, there is no reason to doubt the reliability of the idea of a secular variation in absolute magnitudes of comets.

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[14] See: Konopleva, V.P.: Publikatsii Krimsk. Astr. Observ., No. 5, p. 59, 1953; Cherednichenko, V.I.: Publikatsii Krimsk. Astr. Observ., No. 5, p. 83, 1953; Konopleva, V.P.: Byull. Komissii po Kometam i Meteoram, No. 2, 1953.

[15] See: Vsekhsvyatskiy, S.K.: Fizicheskiye kharakteristiki komet 1954-1960. Fizicheskiye kharakteristiki novykh komet (The Physical Characteristics of Comets of 1954-1960. The Physical Characteristics of New Comets). Moscow, "Nauka", 1966, 1967.

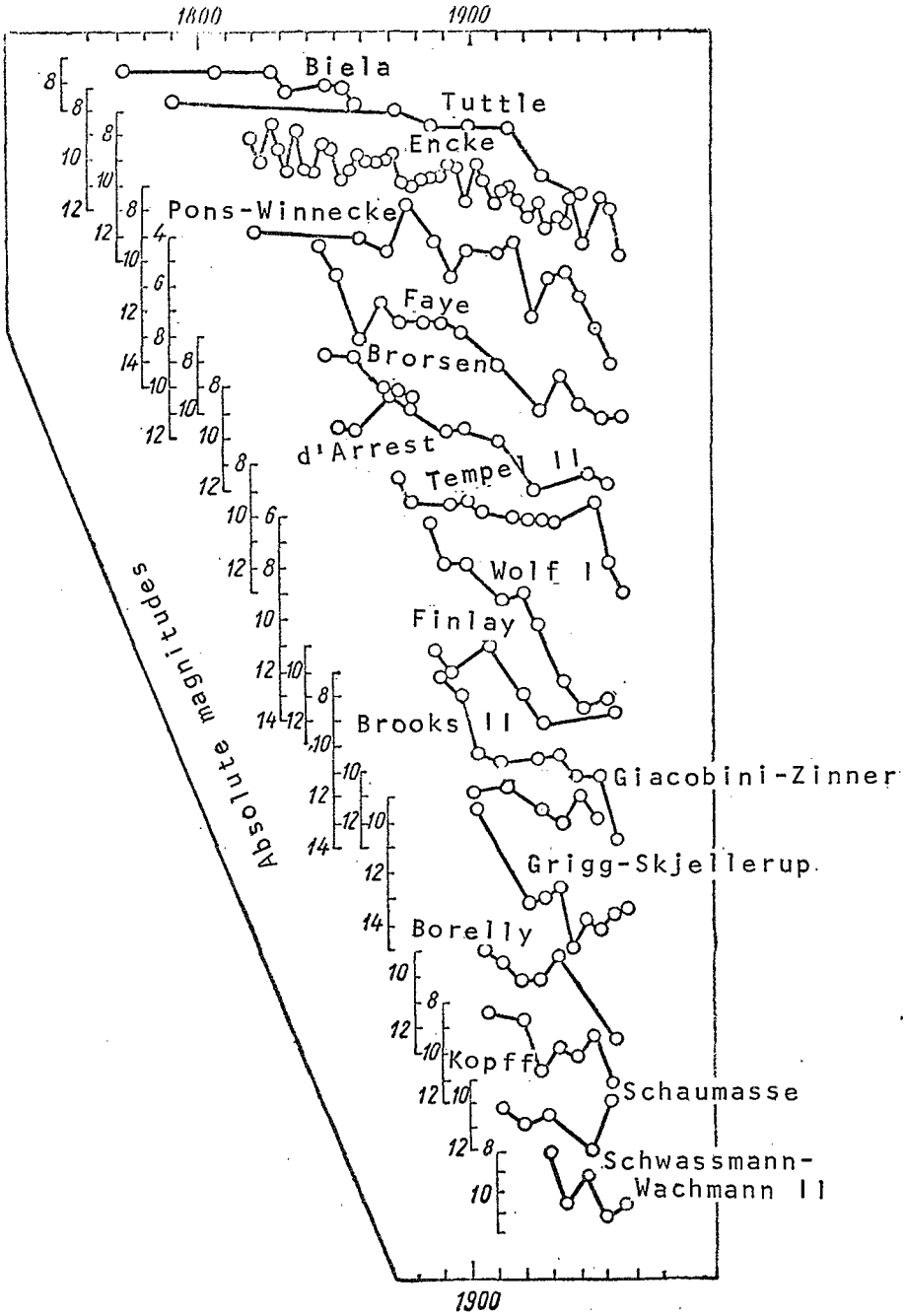

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Fig. 28. Secular Decrease in Brightness of Short-Period Comets (from the study of Z. Sekanina).

In Table 13, we have given the absolute magnitudes of short-period and periodic comets observed in two or more appearances (only the first and last appearances were taken). /100

The data of this table show convincingly that the disintegration or depletion of cometary gases occurs at a very high rate. We must consider that each value of H_{10} was obtained from several tens and sometimes hundreds of estimates. In this regard, the individual characteristics of the observers and the telescopes used affect the data to a very small extent, and the results refer to an average telescope, the standard of which was preserved for at least one century. In addition to the cited comets, note the systematic and rapid decrease in brightness of Comets De Vico-Swift, Pons-Winnecke, Tempel II, Daniel, Reinmuth II, Whipple and Reinmuth I. The systematic diminution of the spherical comets Oterma and Schwassmann-Wachmann I is also doubtless. If we also consider the comets which were observed in only one appearance, which should also be attributed to disintegration and depletion in the majority of cases, the young age of all these short-period comets becomes completely indisputable.

TABLE 13 /101

Comet	Appearance	H_{10}
Encke (P = 3.3).....	1786 I	8.0-9.0
	1964 IV	13.2-15
Honda-Mrkos-Pajdusakova (P = 5.2)....	1954 III	11.6
	1964 VII	14-15
Biela (P = 6.6).....	1772	7.5
	1859	10
De Vico-Swift (P = 5.8).....	1678	6.5
	1965*e*	14.5
Pons-Winnecke (P = 6.1).....	1819 III	8.8
	1964 I	13.5-14
Brorsen (P = 5.5)....	1846 III	7.2-8.2
	1879 I	9.3
Tuttle-Giacobini-Kresak (P = 5.5)....	1858 III	11.3
	1962 V	13.9
Tempel I (P = 6.0).....	1867 II	8.4
	1879 III	10.4
Tempel-Swift (P = 5.7).....	1869 III	11.4
	1908 II	12.8
d'Arrest (P = 6.7).....	1851 II	9.5
	1963 VII	11.5-12.5
Finlay (P = 6.9).....	1886 VII	9.2
	1960 VIII	12.3-15.8
Tempel II (P = 5.3).....	1873 II	8.5
	1962 VI	12.7
Neujmin II (P = 5.4).....	1916 II	10.7
	1927 I	10.7-11.9
Grigg-Skjellerup (P = 4.9).....	1902 II	9-10
	1961 IX	14.9
Kopff (P = 6.3).....	1906 IV	8.4
	1964 III	8.3-12

TABLE 13 (cont'd)

Comets	Appearance	H_{10}
Giacobini-Zinner (P = 6.4).....	1900 III	10.8
	1959 VIII	10.3
Forbes (P = 6.4).....	1929 II	10-11
	1961 VI	13.0-14.3
Perrine-Mrkos (P = 6.5).....	1896 VII	9.9
	1962 I	15.2-15.8
Wolf-Harrington (P = 6.5)*	1924 IV	11.4
	1965 III	12.3
Schwassmann-Wachmann II (P = 6.5)....	1929 I	8.0
	1961 VII	10-11.3
Daniel (P = 6.7).....	1909 IV	9.5
	1964 II	16
Wirtanen (P = 6.7).....	1947 XIII	14.4
	1961 IV	15.3
Reinmuth II (P = 6.7).....	1947 VII	10.9
	1960 IX	14.2
Brooks II (P = 6.8).....	1889 V	7.2
	1960 VI	14.4
Harrington (2) (P = 6.8).....	1953 VI	14.8
	1960 VII	16.3
Arend-Rigaux (P = 6.7).....	1950 VII	12.1 /102
	1964 V	12-14
Holmes (P = 6.9).....	1892 III	0.0-6
	1964 X	13-14
Johnson (P = 6.9).....	1949 II	9.6
	1963 IV	11.0
Finlay (P = 6.9).....	1886 VII	9.2
	1960 VII	12.3-15.8
Borelly (P = 4.0).....	1905 II	9.0
	1960 V	10.7-13.9
Harrington-Abel (P = 7.2).....	1954 XIII	14.8
	1962 II	15.4
Faye (P = 7.4).....	1843 III	4.2
	1962 VII	12.7
Whipple (P = 7.4).....	1933 V	8.0
	1963 II	12.4
Ashbrook-Jackson (P = 7.5).....	1948 IX	7.8
	1953 VI	6-7.7
Reinmuth I (P = 7.7).....	1928 I	10.0
	1965 V	13.0
Arend (P = 7.8).....	1951 X	11.9
	1959 V	14.1
Oterma (P = 7.9).....	1942 VII	7.8
	1960	10.4

* There remains some doubt that Comet Wolf should be identified with Comet Harrington I.

TABLE 13 (cont'd)

Comets	Appearance	H_{10}
Schaumasse (P = 8.2).....	1911 VII	10.3
	1960 III	10.9-13.0
Wolf I-Kamenskiy (P = 8.4).....	1884 III	6.2
	1959 II	13.7
Comas-Sola (P = 8.6).....	1927 III	9.0
	1961 III	11.1
Vaisala (P = 10.5).....	1939 IV	12.2
	1960 IV	13.8
Neujmin (3) (P = 11.0).....	1929 III	10.8
	1951 V	13.7
Gale (P = 11.0).....	1927 VI	9.5
	1938 I	12.0
VanBiesbroeck (P = 12.4).....	1954 IV	9.5
	1966	11-12
Tuttle (P = 13.6).....	1790 II	7.7
	1939 X	11.4
Schwassmann-Wachmann I (P = 16.1)...	1925 II	5.0-0
	1957 IX	6.4-
Neujmin I (P = 18.0).....	1913 III	10.3
	1948 XIII	11.9
Crommelin (Pons-Coggia-Winnecke-Forbes) (P = 28).....	1457 I(?)	6.2
	1956 VI	10.6
Tempel-Tuttle (P = 33).....	1366 (?)	9
	1965 IV	13.5
Coggia-Stephan-Oterma (P = 39).....	1867 I	7.2 /103
	1942 IX	9.5
Westphal (P = 62).....	1852 IV	5.0
	1913 VI	8.8
Brorsen-Metcalf (P = 69).....	1847 V	9.6
	1919 III	9.6
Olbers (P = 69).....	1815	4.3
	1956 IV	5.5
Pons-Brooks (P = 70).....	1812	4.2
	1954 VII	6.1
Halley (P = 76).....	837	0-2
	1910 II	4.6-5.6
C.Herschel-Rigollet (P = 156).....	1788 II	7.1
	1939 VI	8.5
Grant-Grigg-Mellish (P = 164).....	1742	3.7
	1907 II	10.4

We should also mention Comets Kopff, Giacobini-Zinner and Ashbrook-Jackson which kept their original brightness with oscillations during several appearances. It might be expected that the photometric stability of the comet is connected here with the characteristics of the structure of the cometary nucleus, and perhaps with the fragmentary chemical composition of the "ices" of the comets.

The brief duration of the short-period comets and the striking discrepancy in the conclusions of the capture hypothesis and the data of observations prove that the alternative point of view, or Lagrange's hypothesis on the disruption theory for the origin of comets, must be correct.

PART III

DISRUPTION THEORY AND THE PROBLEMS OF THE SOLAR SYSTEM

16. Facts on Comets in the Life of a Planetary Vulcanism

When the facts of the short lifespan of short-period comets and the impossibility of explaining the characteristic features in the orbits of short-period comets or the principle aspects of the system of comets on the basis of the capture theory were established in 1919-1930, the necessary conclusion was that the comets were ejected from the surface of planetary bodies. Obviously, the appearance of temporary existing orbits with short-periods, grouped in planet families, cannot be explained otherwise if the popular hypothesis proves to be unfounded. /104

We must emphasize the determinant role of this argument, as well as the fact that many critics did not lend it enough attention, concentrating their arguments against the relatively secondary, indeterminant aspects of the disruption theory.

In studies during this period [34], I examined different aspects of the problem of the motion of the products of eruptions from the surface of planets, mainly Jupiter, and I found for which initial velocities and under which conditions on the surface of the rotating planets there can arise heliocentric orbits of different types.

It was obvious from the conditions of the problem that, of all the permissible velocities for the eruption, the low velocities should be most frequent. In this regard, the cometary orbits which are most similar to spherical ones, with large perihelion distances, should be the most numerous, while the comets which have orbits with low e and substantial q should be most frequent. This conclusion corresponded best to those characteristics of the orbits of short-period comets of the Jupiter family which contradicted the pattern of the capture hypothesis (the short-period comets generally have eccentricities which are much less than those required by the capture theory, and values of q greater than the theoretical ones).

We find that Comets Holmes and Wolf II (Wolf-Harrington) correspond precisely to the orbits of eruptions emerging from the effective sphere of Jupiter at an angle of θ with the extended radius vector in the vicinity of 270° (in the direction opposing the motion of the planets), while near spherical orbits of the type in Comets Schwassmann-Wachmann I or Oterma corresponded to eruptions at $\theta \approx 90°$. /105

The characteristic aspects of the orbits of short-period and periodic comets and the very existence of comet families prove to be the natural consequence of the disruption idea. It could be

shown that the existence of a limit inclination $i \approx 50°$ for the Jupiter family of comets indicates that the products of the eruptions cannot have larger velocities at the boundary of the effective sphere of Jupiter which greatly exceed $H_{lim} = 3\frac{\sqrt{2m}}{\sqrt{\rho}}$ (m is the mass of the planets; ρ is the radius of the effective sphere).

All the types of orbits observed for the Jupiter family of comets are obtained for the condition $H < H_{lim}$.

At the same time, in examining the velocities on Jupiter itself, it was necessary to allow the existence of very high initial escape velocities on the order of 60 km/sec, which raised doubts 45 years ago. By considering the velocity of rotation of the planets for a surge on the equator, the heliocentric orbits could be obtained for the initial velocities within the range of 47-58 km/sec, but this did not diminish the difficulties.

The researcher was faced with a double dilemma: on the one hand, the characteristics of the motion of short-period comets and their physical instability directly showed that comets come from the Jupiter system, and no other sources of comets except the planet itself were visible in the 1930's; on the other hand, no one then knew of such immense velocities on the Earth, and they therefore seemed completely fantastic.

Velocities of several kilometers per second were noted in the most powerful eruptions on the Earth, and hydrodynamics was not sufficiently advanced to be able to predict the possible occurrences in accumulation of the energy of an explosion. At the same time, the flare phenomena on the Sun and stars were characterized by velocities even 1 order of magnitude higher. Therefore, it was natural that the assumption of Procter and Crommelin concerning Jupiter as the source of comets was repeated in 1931. We now feel only pity for his somewhat hasty hypothesis, although it was not very far from the truth.

After the first very sympathetic responses to the arguments of the disruption theory, they were fairly well forgotten by the end of the 30's, and the disruption theory (it was frequently called the "Vsekhsvyatskiy hypothesis") was connected only with the idea of the ejection of comets from Jupiter. In the light of the new data on the nature of the atmosphere of the planet and the characteristics of its structure, it became less and less probable that the products of eruptions could overcome the gravitational and atmospheric values of the planets, and the idea itself became more and more fantastic. Under these conditions, no one wanted to develop the arguments of Procter, Schulhof, Crommelin and Vsekhsvyatskiy or to look for further ways to solve the problems of comets. On /106
the contrary, there was a tendency to squeeze the facts on comets into certain schemes of the capture hypothesis, to return to the original schools of ideas about comets. All of this delayed an

unbiased investigation of cometary phenomena and the characteristics of the systems of comets by two decades.

Nevertheless, the development of the astronomy of the solar system brought new data which favored the planetary origin of comets, as well as the basic idea of the disruption theory.

After 1931, the following facts were clarified.

(1) The existence of a large quantity of methane and ammonia in the atmospheres of the giant planets above the cloud cover was established (planetary gases doubtlessly in the composition of the parent molecules of the comet), while a large quantity of volcanic gas, or CO_2 was found in the atmospheres of Venus (1932), which also was a characteristic component of cometary gases.

(2) Proof was found that volcanic activity on the surface of the Moon was high in the past (1939).

(3) It is shown that meteoric and meteoritic matter could be formed as the results of its ejection into space during terrestrial volcanic eruptions (V.M. Lodochnikov, 1939; Baum, Vsekhsvyatskiy, Stanyukovich, 1953).

(4) As a result of an investigation of the structure and chemism of meteorites, it was shown and became generally acknowledged that meteorites are fragments of the crust of some planetary bodies (A.N. Zaritskiy, Andrew, et al., 40's).

(5) During 1948-1950, the existence of methane-ammonia ice in cometary nuclei was suspected and shown (S.K. Vsekhsvyatskiy, F. Whipple, P. Swings, etc.), which was one of the clearest proofs of their planetary origin.

(6) The high albedo of the satellites of Jupiter and Saturn, corresponding to reflection from snow or ice, was detected (Kuiper, 1942, 1946).

(7) Atmospheric turbidity was observed repeatedly on Mars, particularly during the period of the 1956 opposition, which indicated directly that there were high-energy volcanic processes. The theory of active vulcanism on Mars was derived (McLaughlin, 1952).

(8) The first precise photographic orbits of meteors showed the existence of meteoric particles and meteoroid showers recently formed in the central regions of the planetary system (1930-1940). This was confirmed even more recently by a large amount of data from photographic and radar observations.

(9) It was shown that there was ice in the composition of Saturn's rings, and consequently, that it was of a cometary-meteoritic nature.

(10) Surveying of the surface of the planets Jupiter, Saturn and Uranus during 1940-1960 showed numerous phenomena which could be explained only as the manifestation of high-energy eruptive (volcanic) processes. /107

(11) The scales of volcanic processes in the history of the Earth were estimated, and it was shown that many data of the geological past can be understood only on the basis of the idea of cosmic vulcanism.

These and many other less obvious facts merely reinforce our certainty in the eruptive origin of comets.

In 1948, V. Kuiper discovered the gaseous atmosphere on Titan, a satellite of Saturn, and on Triton, a satellite of Neptune. Signs of a methane absorption band corresponding precisely in its position and characteristics to the methane band in the spectrum of the planets themselves were noted in the spectra of these satellites. From the point of view of the planetary past of comets, this discovery was of great interest, although Kuiper himself attempted to give an explanation within the framework of the erroneous thermodynamic model. At the same time, it was obvious that if the Jupiter satellites which are closer to the Sun were covered by a frozen atmosphere, or ice, then Titan could have a gaseous atmosphere only because its solid surface was hot. Just as with similar phenomena in the history of the Earth, some section of the surface of Titan could have been covered by a very hot lava stream, which was the result of a regular volcanic cataclysm; therefore, the heat flux inside the satellites keeps the atmosphere in a gaseous state. The same may be said of the distance of Triton.

This activity of the satellites, which was in complete agreement with what was established earlier from a study of the Moon, indicated that the problem of the Jupiter family of comets could be solved.

The satellites of Jupiter could have been the sources of the majority of short-period comets at the present. This assumption was examined in detail, and the results were found to be so advantageous for the hypothesis of satellites that volcanic processes on the Satellites could be spoken of with almost absolute certainty.

In 1949-1950, when we [35] first presented this assumption, the importance of one of the conclusions of the disruption from the Jupiter surface, a change in initial velocity by 0.1 km/sec (instead of 60.1-60.2 km/sec) should bring about the appearance of a comet with retrograde motion, not straight forward motion. The absence of even one comet with retrograde motion from among the Jupiter family also indicated that other sources of comets should be sought in the Jupiter system.

Let us first present some data on the large satellites of planets. Note (in Table 14) the ordered decrease in average density of the Jupiter satellites with the distance from the planets /108 and the relatively low density of Saturn's satellites. The escape velocity on the surface of the satellites proves to be insignificant and varies within the range of 0.5-3 km/sec (velocities of the same order were established for terrestrial eruptions).

TABLE 14

	Diameter d, km	Mass M, g	Absolute Density ρ	Albedo A	Escape Velocity v_e km/sec	Distance from Surface h thous. km	u_0, km/sec	u_0', km/sec
Moon	3476	$7.4 \cdot 10^{25}$	3.35	0.067	2.4	387	2.6	13.3
I Io	3550	7.2	4.5	0.54	2.5	350	6.1	11.4
II Europa .	3100	4.7	3.9	0.73	2.1	600	7.2	13.4
III Ganymede	5600	15.5	2.3	0.34	2.9	1000	5.8	13.2
IV Callisto .	5050	9.7	2.0	0.15	2.4	1813	3.8	11.7
III Tethys .	1000	0.065	1.2	0.77	0.5	234	—	—
IV Dione . .	890	0.103	2.7	0.66	0.6	317	—	—
V Rhea . .	1400	0.22	1.5	0.30	0.7	467	—	—
VI Titan . .	4900	13.7	2.7	0.24	2.8	1163	2.9	9.9
Triton . . .	3700	13.7	5.1	—	3.2	331	2.0	5.4

To estimate the order of magnitude of the velocities necessary for the release of the eruption products from the effective sphere of the planet and the formation of the heliocentric comets, we can assume as a first approximation that the requisite increase in velocity is equal to the difference between the parabolic and spherical velocity for the body on the orbit of the satellite.

If Δ is the distance to the satellite from the planet, then this difference is equal to the following:

$$u = v_\infty - v = \frac{k\sqrt{m}}{\sqrt{\Delta}}(\sqrt{2} - 1) \qquad (75)$$

(m is the mass of the planets).

The velocity at the boundary of the effective sphere of the satellite should be on the same order: therefore, in relative motion,

$$u = k\sqrt{\mu} \cdot \sqrt{\frac{2}{\sigma} - \frac{1}{A}}, \qquad (76)$$

where $\sigma = D\mu^{2/5}$ is the radius of the effective sphere of the satellite in the gravity field of the Sun; A is the semiaxis of the hyperbolic orbit of the product of eruption relative to the satellite.

It follows from the condition assumed that /109

$$-\frac{1}{A} = \frac{m}{\mu\Delta}(\sqrt{2}-1)^2 - \frac{2}{\sigma}; \tag{77}$$

The velocity u_0 at the surface of the satellite is then the following for the formation of a heliocentric orbit of the eruption:

$$u_0 = k\sqrt{\mu}\cdot\sqrt{\frac{2}{\delta}+\frac{m}{\mu\Delta}(\sqrt{2}-1)^2-\frac{2}{\sigma}} \tag{78}$$

(δ is the radius of the satellite).

The satellites under investigation have $\Delta \approx (1 - 12)\cdot 10^{-3}$ AU; $\delta = (0.5 - 3)\cdot 10^{-5}$ AU and $\sigma \approx 10^{-4}$ AU.

For the formation of comets with retrograde motion, the minimum velocity can be obtained from the condition that the relative velocity of the eruption product at the boundary of the effective sphere of the satellite should be greater than or equal to the velocity of the planet on the orbits:

$$k\sqrt{\mu}\sqrt{\frac{2}{\sigma}-\frac{1}{A}} \geqslant \frac{k}{\sqrt{D}}, \tag{79}$$

thus, $-\frac{1}{A} = \frac{1}{D\mu} - \frac{2}{\sigma}$.

The following initial velocity u_0' in this limiting case is then obtained on the surface of the satellite:

$$u_0' = k\sqrt{\mu}\sqrt{\frac{2}{\delta}+\frac{1}{D\mu}-\frac{2}{\sigma}}. \tag{80}$$

The values of u_0 and u_0' are given in Table 14 for a certain satellite.

Sixteen years ago, when these preliminary calculations were published, they were given no attention. At the same time, the data of Table 14 has aided in drawing important conclusions in favor of the disruption concept.

The high values of u_0', which exceed the minimum velocity necessary for the formation of heliocentric orbits (u_0) by a factor of 2 or 3, have explained the absence of retrograde motion in the Jupiter system. The difficulty which we mentioned above (page 102) was thereby eliminated completely.

Moreover, a new explanation was obtained for the characteristic of the distribution of inclinations for comets corresponding to different families. If the initial velocity of the flare on the surface of the satellites u_0 was determined by its characteristics of a planetary body (velocity of the generation of explosive forces, rigidity of the crust shell, etc.), then an approximate equilibrium in the maximum permissible velocity of the flare on the surface could be assumed for satellites of a commensurable mass and size. However, it was then stated that at those velocities which should have given orbits with exceptionally straight forward motion in the Jupiter system, comets with retrograde motion should appear in the system of Neptune comets (where u_0' is equal in order of magnitude to u_0 for the Jupiter satellites). The Neptune family of /110
comets, in which three out of ten members have retrograde motion while two move almost perpendicular to the ecliptic, is also characterized by this feature.

The values of the initial velocities on the order of 2-7 km/sec which completely explained the nature of the orbits of comets observed, could not be considered impossible, since velocities on the same order occurred in terrestrial eruptions. The limiting relationships between the inclination and dimensions of the resultant orbits of the comets in the case of eruptions from satellites proved to be the same as for various calculated ones for the case of comet ejection from the surface of planets.

In connection with these results, which unfortunately remained unnoticed even in 1949, when the Wildt theory of the structure of the outer planets was wide-spread, we gave the following conclusions: "The data on comets require us to reexamine the ideas on the nature of planets and their satellites and to reject the opinion that the outer planets are completely frozen by these, particularly since the latter point of view is based on very shaky positions".

17. Distribution of Orbital Elements in the Disruption Theory

In order to establish the real picture for the theoretical distributions of the orbital elements of short-period comets following from the kinematic scheme of the disruption theory, we calculated orbits corresponding to different escape conditions.

It was assumed that the source of the short-period comets of the Jupiter family was not the planet itself, but the large satellites of Jupiter.

The eruptions can occur in different directions toward the surface and, obviously, on several satellites. At least three satellites of Jupiter have a substantial albedo and may be covered with ices of methane-ammonium compounds; consequently, during volcanic eruptions comets were formed whose characteristic feature is the presence of ice. For different velocities and different directions of velocities of the eruption products on the surface of the satellites, we will have conditions on the boundary of the effective sphere of the planets which are close to uniform distribution of the magnitudes and directions of the relative velocity vectors. Actually, if we consider that the eruption can occur during passage of the satellite between the planet and the Sun (when the velocity of the planet and the orbits of the velocity of the satellites are subtracted) as well as during the movement of the satellites behind the planet (when the orbital velocities are added), then there will be a substantial variance in the distribution of /111
velocity vectors at the boundary of the effective sphere of the planet. Considering the difference in initial conditions and the existence of several activity centers producing the Jupiter comets, it is most natural to assume that the directions and values of the relative velocities are uniformly distributed. If this were not so, for example because of high activity in the equatorial zone of both the planet and the satellites, there would be an accumulation of the vectors near the plane of the planetary orbit, and this would only reinforce the features in the distribution of orbital elements which are characteristic of short-period comets, or concentration around the principle plane of the solar system.

Table 15 gives some supplementary data on Jupiter and its satellites which may be useful in the future.

TABLE 15

	Equatorial Radius, AU	Mass ($M_\odot = 1$)	Velocity in Orbit, km/sec
Jupiter	$4.77 \cdot 10^{-4}$	$0.95 \cdot 10^{-3}$	13.0
I Io	$1.19 \cdot 10^{-5}$	$4.28 \cdot 10^{-8}$	17.0
II Europa	$1.04 \cdot 10^{-5}$	$2.41 \cdot 10^{-8}$	13.7
III Ganymede	$1.87 \cdot 10^{-5}$	$7.60 \cdot 10^{-8}$	10.8
IV Callisto	$1.69 \cdot 10^{-5}$	$4.29 \cdot 10^{-8}$	8.2

The actual velocity of rotation of the equatorial point for Jupiter is equal to 12.6 km/sec. The parabolic relative velocity at the boundary of the effective sphere of the planet (ρ = 0.32 AU) is equal to 2.5 km/sec. We will examine the following problem in relation to the above: we will attempt to find the apparent distributions of the orbital elements of the eruption products which have uniform distribution of velocities and values of the relative velocity vectors at the boundary of the effective sphere of Jupiter if the latter are within certain limits. Obviously, the lower limit should be taken as equal to zero, while the upper limit can be

obtained from the condition of the absence of orbits with retrograde motion and parabolas. This corresponds to a relative velocity of about 8.5 km/sec. The center of the distribution of relative velocities is assumed to coincide with the center of the planets (i.e., the dimensions of the effective sphere are considered to be small compared to the distance of the planets from the Sun). The planet is assumed to move along a sphere of radius D. The effect of attraction of the planets is assumed to be small beyond the limits of the effect of the sphere, and we will disregard this. These simplifications, which were also assumed in the statistical capture theory, cannot introduce fundamental distortions into the distributions of the elements.

Let us call the relative velocity of the flare at the boundary of the effective sphere of the planets H. The condition of the outburst coincides at the initial moment with the position of the planet, according to all conditions. Let us select the system of coordinates with origin at the Sun so that the x axis coincides with the direction to the planets at the initial moment, the y axis is in the plane of the planetary orbits and the direction of its motion, and the z axis is directed towards the pole of the planetary orbit. Then, calling ξ, η, ζ the velocity components of H, we will have the following for the moment $t = 0$ ($h = \frac{1}{\sqrt{D}}$ is the velocity of the planets in orbit): /112

$$x_0 = D; \quad y_0 = 0; \quad z_0 = 0;$$
$$x_0' = \xi; \quad y_0' = h + \eta; \quad z_0' = \zeta. \tag{81}$$

Introducing the spherical coordinates λ and β, we can write the following:

$$\begin{aligned} \xi &= H\cos\lambda\cos\beta, \\ \eta &= H\sin\lambda\cos\beta, \\ \zeta &= H\sin\beta. \end{aligned} \tag{82}$$

Here β is the angle of the relative velocity vector with respect to the plane of the orbit (which changes in the range from +90° to -90°); λ is read off from the extended radius vector in a counterclockwise direction from 0° to 360°).

Using known relationships, we find the following:

$$y_0 z_0' - z_0 y_0' = \sqrt{p}\ \sin i \sin \Omega = 0, \tag{83}$$
$$x_0 z_0' - z_0 x_0' = \sqrt{p}\ \sin i \cos \Omega = DH\sin\beta, \tag{84}$$
$$x_0 y_0' - x_0' y_0 = \sqrt{p}\cos i = D\left(\frac{1}{\sqrt{D}} + H\sin\lambda\cos\beta\right) \tag{85}$$

(i and Ω refer to the plane of the planetary orbit). It follows from (84) and (85) (assuming that $\Omega = 0°$ or $180°$) that

$$\tan i = \frac{H \sin \beta}{\frac{1}{\sqrt{D}} + H \sin \lambda \cos \beta} = \frac{\zeta}{h + \eta}, \tag{86}$$

$$p = D^2 \left(H^2 \sin^2 \beta + H^2 \sin^2 \lambda \cos^2 \beta + \frac{2H}{\sqrt{D}} \sin \lambda \cos \beta + \frac{1}{D} \right) =$$
$$= D^2 [\zeta^2 + (h + \eta)^2]. \tag{87}$$

Furthermore, since the heliocentric velocity v is determined from the expression:

$$v^2 = h^2 + H^2 + 2Hh \sin \lambda \cos \beta = H^2 + \frac{1}{D} + \frac{2H}{\sqrt{D}} \sin \lambda \cos \beta, \tag{88}$$

then, consequently, /113

$$\frac{1}{a} = \frac{1}{D} - H^2 - \frac{2H}{\sqrt{D}} \sin \lambda \cos \beta;$$

and, knowing p and a, we can obtain the following:

$$e = \sqrt{1 - \frac{p}{a}} \tag{89}$$

$$q = a(1 - e). \tag{90}$$

Considering the assumption that the magnitudes and directions of the velocities are distributed uniformly for every value of H from 0.01 to 0.27 (in units of k), we calculated the elements of the heliocentric orbits for different values of λ and β every 0.02. In this case, we use values of $\lambda = 0°$, $30°$, $60°$, $90°$, $120°$, $150°$, $180°$, $210°$, $270°$, $300°$, $330°$ and, for each of them, values of $\beta = 0°$, $\pm 15°$, $\pm 30°$, $\pm 50°$ and $\pm 90°$, which corresponds to uniform distribution of the directions. Thus, we calculated more than 720 orbits, which allowed us to formulate a general representation of the characteristics of the theoretical distributions of the elements.

In order to obtain distributions which could be compared to observations, it was necessary first of all to consider the effect of observational selection. For this, the distribution of absolute magnitude of short-period comets could have been used, considering the conditions for discovering the comets. However, for the approximate theory we are presenting, it was sufficient, as is usually the

case, to consider the apparent orbits for only those which had perihelion distances less than some extreme value q. The calculations of the quantity of the theoretical orbits inside the corresponding intervals for the values of elements can be carried out for two assumptions:

(I) All the comets which ave perihelion distance of $q < 2$ AU can be discovered;

(II) All comets with $q < 3$ AU can be discovered;

In the first case, in order to explain the stability in the characteristic aspects of the distributions, the calculations were carried for three boundary values: $H = 0.23$, 0.25 and 0.27 ($i < 50°$). The total number of 68 short-period comets discovered before 1956 includes initial Comets Schwassmann-Wachmann I 1925 II, which doubtless has a connection with the Jupiter system. Comets Encke and 1949 III Wilson-Harrington, which apparently are not connected with the Jupiter system, were excluded from the calculations.

A comparison of the observed and theoretical distributions of the elements corresponding to a boundary value of $H = 0.23$ is given (in a uniform scale) in Figures 29-32.

In examining the figures, we should notice a very good correlation in the orbital characteristics which follow from the hypotheses of the disruption theory and the distributions observed. We must call attention to the fact that we are considering the effect of observational selection only in a most approximate way (introducing the condition $q < 2$ AU). The inequality in the absolute magnitude of the comets, which for the first appearances we examined varied from $H_{10} = 4.2^m$ (initial Comet Faye) to $H_{10} = 13 - 14^m$ (Comets Neujmin-Jackson and 1953 e), should show up in the distribution observed. /114

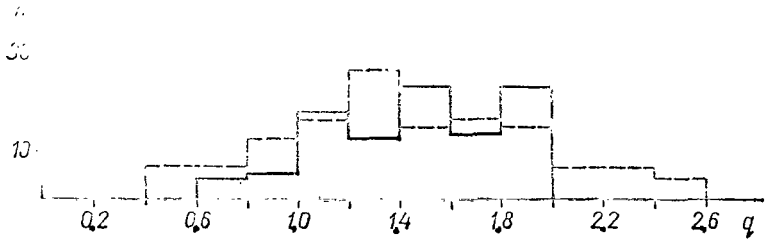

Fig. 29. Theoretical and Observed (Dotted Line) Distribution of Perihelion Distances ($q < 2$ AU).

We have already mentioned that the scheme used to calculate the theoretical distributions is approximative and does not consider the dimensions of the effective sphere of the planets, or the effect

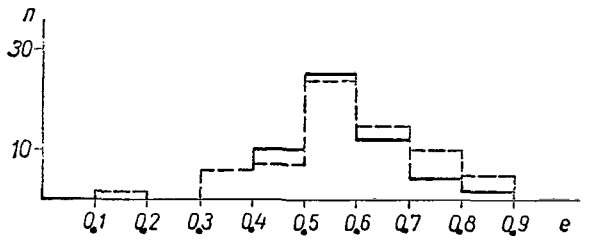

Fig. 30. Theoretical and Observed (Dotted Line) Distribution of Eccentricities (q < 2 AU).

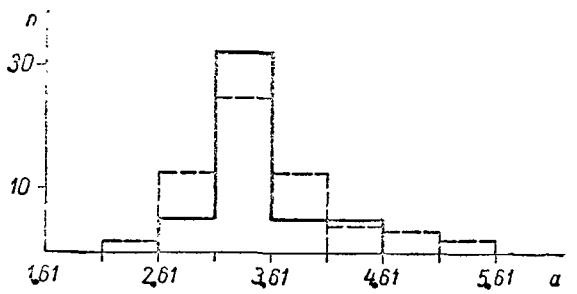

Fig. 31. Theoretical and Observed (Dotted Line) Distribution of Semiaxes (q < 2 AU).

of subsequent perturbations which, however, cannot change the general picture. We could also have spoken of other distributions of the vectors of H. The variable of the problem in the calculations (values of λ and β) changed every 30-40°, i.e., very substantially, which brought about a relatively small number of cases in different intervals of the elements, and which was the reason for the manifestation of fluctuations in the theoretical distributions (for example, in the distribution over q). Nevertheless, despite all the effects cited, we must acknowledge the remarkable, almost complete similarity between the theoretical and observed curves for the distribution of elements of short-period comets. It is impossible to explain the correlation of the maxima in the distributions of perihelion distances and inclinations, in terms of arbitrariness. As can be seen, the best correlation is achieved for the limit value of H = 0.23. The simultaneous agreement in the distributions of eccentricities, semiaxes, and values of the greatest angles of inclinations of the orbits in the Jupiter family of comets, based on the most natural assumptions concerning the uniform distribution of the relative velocity vectors and the existence of a limit value H, is a very convincing proof that the principle positions of the disruption theory are correct. The distributions observed in the system of short-period comets cannot be obtained for any alterations of the scheme of the capture theory. /115

The predominance of orbits with small inclinations (in the vicinity of values of 0-5°) in the theoretical distribution, compared to the observed ones, may be the result of disregarding the

real inclination of the plane of motion of the generatrix of the Jupiter system to the ecliptic. On the other hand, the effect of the visibility conditions is also very probable here, since the discovery of comets with low i is less probable, under otherwise equal conditions, because of the interference produced by the twilight cones. These conditions can affect the distribution of inclinations observed. /116

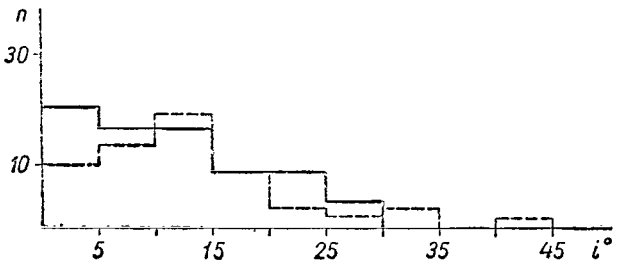

Fig. 32. Theoretical and Observed (Dotted Line) Distribution of Inclinations (q < 2 AU).

The distributions for the condition of q < 3 (Figs. 33-35) differ significantly from those for short-period comets, although the general nature is preserved. There is a substantial predominance of great perihelion distances. The maximum in the distribution of eccentricities is shifted toward the range of lower values of e (0.3-0.4). The predominance of small inclinations is even more sharply pronounced. The maximum in the distribution of semiaxes is shifted toward the range of higher a (3-4).

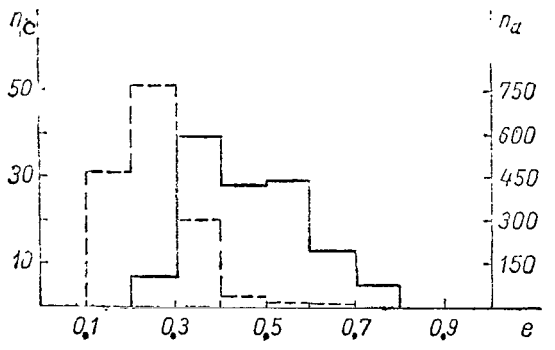

Fig. 33. Distribution of Asteroids n_a (Dotted Lines) and Comets n_c by Values of Their Eccentricities (q < 3 AU).

We must not forget to say that these aspects of the distributions relating to different conditions of visibility and observational selection correspond exactly to that nature of the distributions of elements of asteroids which has been repeatedly noted in a comparison with the cometary distributions [36]. We are presenting the distributions observed for asteroids, together with the theoretical distributions, in Figures 33-35; their general correlation serves as a further continuation of the idea that both groups of small bodies are related, and can serve as a /117

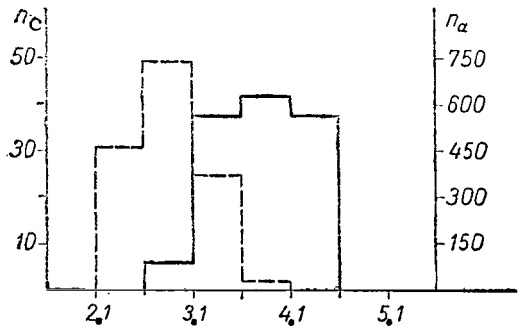

Fig. 34. Distribution of Asteroids n_a (Dotted Lines) and Comets n_c by Values of Their Semiaxes (q < 3 AU).

proof of their common manner of development in the solar system. As regards these results of the statistics of comets and asteroids, it must be found whether or not it is true that the origin of short-period comets which A.D. Dubyago [37] suggested may be explained by assuming that the comets are condensed in the zone of movement of Jupiter and then, as a result of perturbations from the planets, are directed toward the visibility range in the form of short-period comets.

This explanation does not take account of the following factors. Masses of ice and gas which exist for a long period of time cannot be found in the zone of motion of Jupiter and even further away from the Sun, since they should be "swept out" of this region of the solar system by the effect of solar radiation, corpuscular bombardments, the effects of bremsstrahlung, etc. Thus, if a gaseous-dusty medium exists at the distance of Jupiter, it should be continuously replenished, and at a very rapid rate. However, it does not actually exist in that quantity necessary for condensation, and this proves the absence of gaseous and dusty atmospheres for many distant asteroids with complete certainty. Such large bodies as the Trojans, for example, should have condensed the gases and converted into comets much more rapidly than ordinary objects of this type. Finally, if the effects of condensation did take place, a gradual increase in the brightness of comets should have been noticed, even if in isolated cases. Actually, the rapid disintegration of short-period comets and the diminution of comets of the Neptune family are observed. Therefore, the assumption of condensation in the Jupiter-Saturn zone is completely erroneous. /118

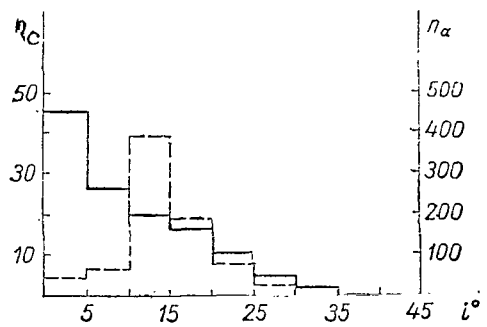

Fig. 35. Distribution of Asteroids n_a and Comets n_c (Dotted Lines) Over Magnitudes of Inclinations (q < 3 AU).

The close correlation in the theoretical and observed distributions of the orbital characteristics of the short-period comets shows that we are concerned here with young formations which have just arisen in the Jupiter system, moving along orbits which are still only slightly distorted by perturbations and which therefore reflect the relations towards the orbit of this planet.

The Jupiter family of comets is not the only one in the solar system. The characteristics of the cometary groups in Saturn, Uranus, and Neptune have a similar explanation.

A comparison of the theoretical and observed distributions indicates that, during the last two centuries, the short-period

comets were formed as the result of eruptive processes in the Jupiter system, while the magnitude of the relative velocity at the boundary of the effective sphere did not exceed $H = 0.23$ (i.e., 6.9 km/sec) on the average. This corresponds to the maximum permissible velocity on the surface of the satellites.

The total number of cometary objects ejected from the Jupiter system in 200 years can be estimated as approximately 600-800 on the basis of the number of short-period comets known to this time. The change in actual number of comets of the Jupiter family as a function of the value of the perihelion distance is represented by the expressions: $n = 6.0 \cdot q^{0.9}$ (q = 1 - 4 AU) and $n = 1.45 \cdot 10^{-5} q^{10.2}$ (q = 4-5.3 AU). Consequently, 3-4 eruptions occur in the Jupiter system every year, which gives a sufficient quantity of matter for an average short-period comet.

18. The Scales of Processes on Jupiter's Satellites

We will use the following designations: δ is the radius of the spherical body of the satellite, μ is its mass, σ is the radius of the effective sphere, Δ is the radius of its orbit (assumed to be spherical) around the planet, and D is the radius of the planetary orbit [38].

We then have the following for the initial velocity of the flare u on the surface of the satellite:

$$u^2 = k^2\mu\left(\frac{2}{\delta} - \frac{1}{A_S}\right), \tag{91}$$

where A_S is the semiaxis of the hyperbolic orbit of the eruption relative to the satellite.

The velocity v_σ at the boundary of the effective sphere of the satellite can be obtained by the following:

$$v_\sigma = k^2\mu\left(\frac{2}{\sigma} + \frac{u^2}{k^2\mu} - \frac{2}{\delta}\right). \tag{92}$$

Since σ is on the order of $10^{-2}\Delta$, we may assume that, at a distance of Δ from the planets, the velocity of the eruption products relative to the planets V_Δ can be determined from the following expressions: /119

$$V_\Delta^2 = v_\sigma^2 + v^2 + 2v_\sigma v\cos\psi. \tag{93}$$

Here ψ is the angle between the direction of orbital motion of the satellites and the direction of the relative velocity of the erup-

tion product at the boundary of the effective sphere, while $\nu = \frac{k\sqrt{m}}{\sqrt{\Delta}}$.

Continuing a transition to the heliocentric velocity at the boundary of the planet's effective sphere, we find that $V_\rho^2 = km\left(\frac{2}{\rho} + \frac{V_\Delta^2}{k^2 m} - \frac{2}{\Delta}\right)$ or, after substitutions,

$$V_\rho^2 = k^2 m\left[\frac{2}{\rho} + \frac{2\mu}{m\sigma} + \frac{u^2}{k^2 m} - \frac{2\mu}{m\sigma} - \frac{1}{\Delta} + \frac{2u}{k^2 m}\cos\psi\right] \qquad (94)$$

This expression allows us to evaluate the magnitude of the relative velocity at the boundary of the planet's effective sphere as a function of the initial velocity on the surface of the satellite (u) and the position of the flare on the orbit of the satellite (ψ).

Taking the mean values for Δ, μ and other quantities in the systems of the satellite ($\Delta \approx 10^{-2}$ AU; $\mu \approx 0.5\cdot 10^{-7}\ M_\odot$; $\delta = 1.4\cdot 10^{-5}$; $\sigma \approx 10^{-4}$) and assuming that the maximum value of $u = 0.2k \approx 6$ km/sec and $\cos\psi = 1$ (which corresponds to the limit value of $i = 45°$ in the system of Jupiter Comets), we can obtain the following maximum values of V_ρ: for Jupiter (Callisto) 0.279; for Saturn (Titan) 0.273; Uranus 0.270; Neptune (Triton) 0.236.

Since the boundary value of u = 6 km/sec corresponds to the orbital characteristics of short-period comets of the Jupiter family, the reduced values of V_ρ correspond to the concept that there is approximate equality in the physical conditions of the satellites in the systems of other planets at the time of the formation of the comets of the given planet. The latter must be kept in mind, since the "age" of the comets of Jupiter is obviously different from the age of the comets of the Neptune or Uranus family. We may assume that only the short-period comets of Jupiter are the youngest comets of our time.

Using (86)-(90), we can make a qualitative estimate of the elements of the orbits of the flare products as a function of the conditions on the boundary of the effective sphere of the planet:

$$\tan i = \sqrt{D}\,V_\rho \sin\beta\left(1 + V_\rho\sqrt{D}\sin\lambda\cos\beta\right)^{-1}, \qquad (95)$$

$$p = D^2 V_\rho^2(\sin^2\beta + \sin^2\lambda\cos^2\beta) + 2D^{\frac{3}{2}}V_\rho\sin\lambda\cos\beta + D, \qquad (96)$$

$$\frac{1}{a} = \frac{1}{D} - V_\rho^2 - 2V_\rho D^{-\frac{1}{2}}\sin\lambda\cos\beta. \qquad (97)$$ /120

In order to compare cometary systems of different planets, we must select out of all the possible orbits only those which are observed from the Earth, i.e., which enter into the visibility sphere. As before, we will use the condition of $q \leq 2$ AU. The boundary surface in the velocity space v which separates comets with perihelion distance $<q$ can be obtained from the following expressions:

$$v^2 = \frac{2}{D} - \frac{1}{a} \text{ and } p = D^2 v^2 \sin^2 \varphi = q\left(2 - \frac{q}{a}\right).$$

Excluding a (ϕ is the angle between the resultant heliocentric velocity and the radius vector at a distance approximately equal to D), we find that

$$v^2 = \left(\sin^2 \varphi - \frac{q^2}{D^2}\right) = \frac{2q}{D^2}\left(1 - \frac{q}{D}\right). \tag{98}$$

This is the equation for a hyperboloid with real semiaxis B determining the unit value of the velocity vector normal to the radius vector ($\phi = \pm 90°$) which also gives the visible comet:

$$B = \frac{\sqrt{2q}}{\sqrt{D(D+q)}}; \tag{99}$$

The imaginary semiaxis of the hyperboloid

$$A = \sqrt{\frac{2}{qD}(D-q)}. \tag{100}$$

The angle between the asymptote and the radius vector is determined in the following way:

$$\tan \nu = \frac{B}{A} = \frac{q}{\sqrt{D^2 - q^2}}. \tag{101}$$

Table 16 gives mean values of the magnitudes characterizing the surface which separates the visible comets for the giant planets, in the limiting case $q = 2$.

TABLE 16

Planets	D	B	A	$\tan \nu$	$\sqrt{\frac{2}{D}}$	$\frac{2q}{D^2}$
Jupiter	5.20	0.326	0.735	0.416	0.620	0.418
Saturn	9.54	0.192	0.904	0.214	0.458	0.0441
Uranus	19.2	0.160	0.947	0.105	0.322	0.0118
Neptune	30.1	0.064	0.966	0.067	0.258	0.0042
Pluto	39.5	0.049	0.969	0.051	0.223	0.0026

In view of the scheme we have selected (initial velocities of the eruption products at the surface of the satellites approximately identical, and not exceeding 6 km/sec), we arrive at the following geometric interpretation of the problem. /121

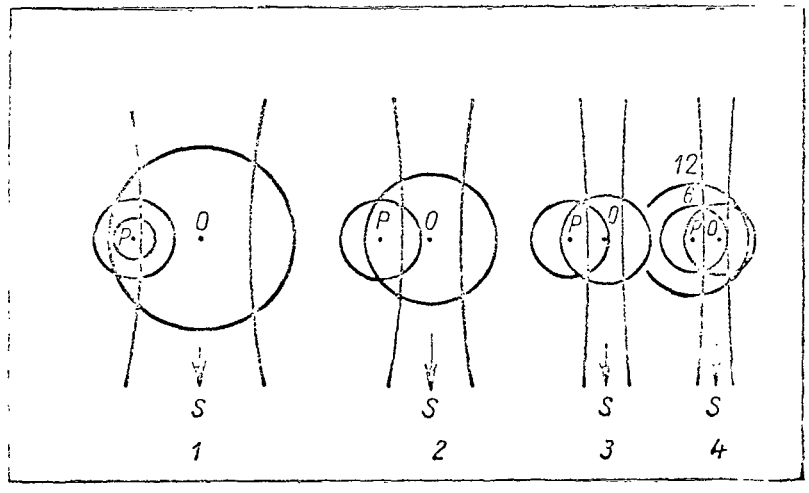

Fig. 36. Diagram of the Visibility (For Discovery) of Different Types of Orbits For the Eruption Products in the Systems of Jupiter (1), Saturn (2), Uranus (3) and Neptune (4).

We will assume that the distribution of vectors of V_ρ is close to spherical in the velocity space around the planets P. Because of the fact that the planets move at a velocity of $\sqrt{1/D}$, the center of the distribution of V_ρ is displaced with respect to the center of the hyperboloid by a value of $\sqrt{1/D}$ in the direction $\phi = 90°$. Figure 36 (1) shows the positions of the centers of P and O and the boundary curves in the plane of the planetary orbits. The values correspond to the data for Jupiter (satellites Europa and Callisto). The large circle with center at O has a radius of $(2/D)^{1/2}$ and divides the regions of elliptical and hyperbolic orbits. The figure clearly shows that all the visibile comets of Jupiter (for the condition $u \leq 6$ km/sec) are elliptical, since the sphere of P (radius of V_ρ) is completely within the sphere of O (for Europa) or almost completely (for Callisto). Only a small number of the comets formed in the Jupiter system passes into the visibility range ($q \leq 2$), about 1/20 in the case of eruptions on satellite II and no more than 1/5 for satellite IV. All the comets have a straight forward motion, since the apexes of the vectors are to the left of the plane OS, /12 which is normal to the plane of the planetary orbits and to the direction of its orbital velocity. All the initial heliocentric velocities of the visible comets are found to be only a little less than B.

We have the following maximum and minimum heliocentric velocities for these comets (see Table 17):

TABLE 17

	v_{min}	ϕ	v_{max}	ϕ	
Satellite Europa	0.320	90°	0.346	76°	140°
Satellite Callisto	0.159	90°	0.426	50°	130°

Since $V^2 = \frac{2}{D} - \frac{1}{a}$, then $a = \frac{D}{2 - Dv^2}$.

Thus, the limit values of a are equal to 3.54 and 3.80 for Europa, and 2.79 and 4.93 for Callisto.

Similarly,

$$\tan i_{max} = V_p (D^{-1} - V_p^2)^{-\frac{1}{2}}. \quad (102)$$

Therefore, i_{max} proves to be the order of 16° for the flares of Europa and order of 39° for the comets of Callisto; this corresponds almost precisely to the limit i observed in the system of Jupiter Comets.

The limit values of ϕ are given in Table 17, and the corresponding limit values for the eccentricities are therefore determined from the following expression:

$$e = \left[1 - \left(\frac{2}{D} - v^2\right) v^2 D^2 \sin^2 \varphi\right]^{\frac{1}{2}}. \quad (103)$$

We find that e_{max} = 0.46 and 0.60 for Europa, and e_{max} = 0.92 and 0.77 for Callisto.

The minimum values for the perihelion distances can be found from the following expression:

$$q = a(1 - e) = \frac{D}{2 - Dv^2}\left[1 - \sqrt{1 - (2 - Dv^2) v^2 D^2 \sin^2 \varphi}\right]. \quad (104)$$

For the corresponding values given in Table 17, we find that q_{min} = 1.88 (for Europa) and q_{min} = 0.37 (for Callisto).

These limit values of the elements and the characteristics of the orbits of the comets of the Jupiter group correspond very satisfactorily to the data obtained from observations. We have obtained a good correlation even in that rough approximation when the term "visibility sphere" was used without regard for the absolute magnitudes of the comets, and with the assumption that there was a general limit value for the initial velocity. It cannot be said /123
that this complete correlation of the semiaxes, inclinations and eccentricities, for only one assumption (that u = 0.2, $k \approx 6$ km/sec)

is coincidental.

The mean value of the heliocentric velocity of v for the vectors under investigation proves to be on the order of 0.23 and, consequently, the value of $s = v/v_{lim}$ (Newton's characteristics) for the orbits of the eruptions prove to be equal to $s = 0.23/0.44 = 0.52$; this corresponds completely to the fact noted by Van Woerkom, that the distributions of s for short-period comets are grouped around a value of 0.5.

Figure 36 (2, 3, 4) gives similar diagrams for the systems of Saturn, Uranus and Neptune. The center of the distribution of limit velocities at the boundary of the planet's effective sphere is at point P (with the initial data for Titan, Titania and Triton).

From this the initial limiting velocity on the surface of the satellite is assumed to be equal to 6 km/sec. A sphere with a center at point O divides the elliptical and hyperbolic comets, since the surface of the hyperboloid distinguishes all "visible" comets ($q \leq 2$ AU); the distance OP in the correct scale corresponds to the orbital velocities of the planets.

An examination of the diagrams depicted in Figure 36 (1, 2, 3, 4), which must be represented in the form of projections of the volumetric picture, clearly shows us the characteristics of the resulting orbits of the disruption products in the systems of different planets.

In the Jupiter system, all of the boundary surfaces of P occur in the range of straight forward motion, as well as almost solely elliptical (and spherical) resultant orbits. It is natural to assume that the number of vectors corresponding to low relative velocities would be higher, i.e., that the density of distributions of P increases toward the center. We should then expect a substantial number of comets with nearly spherical orbits in the Jupiter system, comets which do not enter the range of the visibility hyperboloids. Of all these comets with vectors in the vicinity of P, only the particularly bright objects can be detected; Comets Schwassmann-Wachmann I and Oterma undoubtedly belong to this group. Actually, the number of such comets moving in the region of Jupiter's orbit should be (if we base our arguments on the distribution of absolute magnitudes of the parabolic comets) hundreds of times higher ($H_{10} = 9^m\text{-}13^m$); they lose their reserves of gases slowly and, as a result of convergences with the planets, can gain or lose the momentum and either become visible comets or depart from the solar system at hyperbolic velocities.

In our scheme, a small number of ejections from the Jupiter system have parabolic and hyperbolic orbits with $q \approx 5$ AU: these comets are formed because of the section of the distribution of P (Callisto) which protrudes beyond the surface of the sphere of O /124 corresponding to heliocentric parabolas.

Pertaining to the picture characterizing the conditions of the Saturn system (Titan), we can see that here again there are no orbits with retrograde motion; however, many of the comets can have substantial angles of inclination which are close to 90°. If we consider the possibility of eruptions from the surface of Iapetus, which correspond to a high value of the limit velocity V_ρ, then there should also be rare comets of the Saturn family with retrograde motion.

Together with predominating orbits with straight forward motion, comets with retrograde motion should also appear in the system of Uranus. For Neptune, the percentages of orbits with straight forward and retrograde motion are very close. The average theoretical values of the return periods for the planet families are the following: 6.1 years (Jupiter), 12.9 years (Saturn), 35.9 years (Uranus), 72.6 years (Neptune); this agrees well with the observations.

One more important circumstance can be established from the visibility diagrams: comets with large inclinations should correspond to lower velocities v and angles ϕ which deviate greatly from 90° (for example, the values of ϕ for Uranus can reach 0° or 180°). Therefore, in the systems of Saturn and Uranus, high inclinations should correspond to lower values of the orbital parameter $p = D^2v^2\sin^2\phi$ and lower values of q in general.

In the Neptune system the relationship between q and i should be less pronounced or should be absent, since the numbers of comets with straight forward and retrograde motion approach each other here. These general theoretical conclusions are confirmed by the distributions observed for different groups of comets over i (see Fig. 4), as well as the following average values of $\bar{q}$: for the Saturn system $\bar{q} = 1.94$ for five comets ($i < 30°$), $\bar{k} = 1.01$ for three comets ($i > 30°$); for the Uranus system, $\bar{q} = 1.16$ for two comets ($i < 30°$), $\bar{k} = 0.98$ for one comet ($i > 30°$), for the Neptune system: $\bar{q} = 1.07$ for five comets ($i < 50°$), $\bar{k} = 0.60$ for five comets ($i > 50°$).

We can see that an examination of the disruption theory from the point of view of its kinematic consequences leads to a more than reassuring result, transforming the initial assumptions into certitude. We can say this with assurance, since the fact that we know about the physical characteristics of the comets is a definite argument for the disruption theory, as is the complete invalidity of attempts at explaining the orbital characteristics of the system of comets on the basis of the assumption concerning large perturbations or diffusions.

An investigation of comets and other groups of small bodies shows the high volcanic activity of many planetary bodies of the solar system.

The inner planets (Mercury and Venus) should be a source of small bodies; this is indicated by the existence of short-period meteroid showers and Comets Encke and Wilson Harrington. However, the densely-populated cometary system of Jupiter indicates that the greatest activity is maintained presently in the Jupiter system. The Saturn system is also very active, while we still know of only three comets of the Uranus family; it is possible that the latter is connected with the anomalous rotation of this planet (it moves around the Sun as if lying on its side). These conclusions were drawn in 1931-1933, and then on a new basis in 1949-1950.

We will examine direct observations which affirm the conclusions of cometary astronomy at a later time. However, let us first acquaint ourselves with the criticism of the disruption theory.

In 1890, Tisserand, discussing Lagrange's hypothesis, solved the problem of the transformation of a spherical planetary orbit into the orbit of a comet and concluded that the formation of a system of parabolas requires the satisfaction of very strict conditions relative to the initial impulse. At the same time, Tisserand considered Lagrange's idea on the formation nuclei to be probable.

The results of our analysis of the kinematic scheme of the disruption theory have eliminated Tisserand's arguments completely.

In 1938, A. Corlin raised doubts that there could be high initial velocities, bearing the location of Jupiter in mind, and he attempted to show that, when atmospheric resistance is considered, they could attain all the conceivable limits. Because of the development of hydrodynamics and the practice of jet motion during the last three decades, the possibility of obtaining velocities of the order of ten kilometers per second was realized, it was proven that the "piercing" of the atmosphere of a planet during the flight of massive bodies occurs with almost no loss of velocity [38].

It was shown earlier that for high initial velocities, or for high activity of planets which are far removed from the Sun, long-period, parabolic and hyperbolic comets should have arisen. The existence of the maxima on the distribution curve (for P = 502,000 years) gives us reason to assume that there are distant planets (if not now, then in the past) which could produce both comets with straight forward and those with retrograde motion with equal probability, and for relatively low initial velocities.

Considering the absence of sharply hyperbolic orbits from among the comets observed, we may conclude that, at present, the initial velocities do not reach those values at which comets arose in the past. We are living in a period of relative quiescence in the state of planetary bodies, observing the returns from the boundaries of the solar system of comets which were ejected hundreds of thousands and millions of years ago. As the disruption theory shows, this is

why comets allow us to explain the remote history of the planetary system. /126

The distribution of comets observed around the parabolic limits is explained simply and naturally from the point of view of the disruption concept. The facts indicate that there is rapid disintegration, depletion and disappearance of the comets; that is why the short-period and periodic comets now observed should be very recent formations. However, the parabolic comets relate to a period of high volcanic activity in the solar system, when not only near parabolical comets arose, but also hyperbolic comets abandoning the solar system.

The present state is characterized by the existence of young, short-period and periodic comets now formed for low limit velocities mainly on the satellites of giant planets, and a number of comets formed millions of years ago in regular high-energy cataclysms; these comets disintegrate depending on the characteristics of their orbits.

The rate of loss of gaseous material and absolute brightness is a function of the orbital parameter: $\Delta J \sim \frac{2\pi A}{k\sqrt{P}}$. The total loss of luminosity during the prolonged existence of a comet is determined by the number of revolutions and is in inverse proportion to P or P^n. It is obvious that the number of comets we now observe depends on their absolute brightness, and for the comets which are accessible to observations (in the visibility range, subjected to the disintegrating effect of solar rays), the initial distribution is altered depending on the dissipation function $\Phi = (\frac{P}{P_0})^{\lambda}$; here P_0 is the maximum limiting period of the rotating comets (which do not undergo substantial perturbations from neighboring stars) and λ is generally close to 1 if the disintegration differs insignificantly from the law of inverse proportionality of r^2. Therefore, if the initial distribution of the long-period comets, formed practically instantaneously during a period of great flare-up of vulcanism, was uniform in the range of $1/a$, then the distribution in the time measured by the maximum permissible period (P_0) of a rotating comet [(50-100)$\cdot 10^6$ years] should change substantially because of the disintegration and disappearance of a substantial number of the comets with lesser periods.

In this case, the resulting distribution is defined as $n = \Phi n_0$ (if n_0 signifies the number of comets for maximum values of T).

Table 18 gives both our theoretical distributions and the observed distributions taken from the studies of Oort.

We can see that the disintegration concept can completely explain the absence of a large number of comets with average values for the return periods, with which the capture theory cannot cope.

TABLE 18

/127

$\frac{1}{a}$	P (thous. years)	$\Phi = \frac{P}{P_0}$	Observed Numbers of Comets	Theoretical Numbers of Comets for the Eruption Scheme
0.00000 — 0.00050	> 89	1.000	24	24
0.00050 — 0.00100	89 — 32	0.185	3	4.4
0.00100 — 0.00200	32 — 11	0.062	3.2	1.5
0.00200 — 0.00400	11 — 4	0.023	3.6	0.6
0.00400 — 0.01000	4 — 1	0.009	5.5	0.22
0.01000 — 0.02000	1 — 0.36	0.002	2.0	0.05
0.02000 — 0.04000	0.36 — 0.12	0.001	1.8	0.02

On the other hand, the prevalence of the observed numbers over the theoretical numbers for comets with periods from 11,000 to 120 years (by a factor of 10's and even 100's) can be explained fully by the fact that a large number of such comets were formed much later than the first cataclysms and in the ever-decreasing force of the volcanic processes on planetary bodies.

The author is certain that a detailed analysis of the orbital elements and other characteristics of the cometary system will subsequently establish the principle stages in the development of the solar system and the history of planets, including our Earth.

19. Small Bodies, The Nature of the Processes on Planets and the Disruption Theory

An investigation of comets and the conclusions of the disruption theory indicate that the eruptive processes on planets played an immense role during individual periods in the development of the solar system. These processes should have had extreme cosmogonical importance, and it is obviously impossible to explain the past history or the present characteristics of the solar system without considering them.

The well-established cases of a connection between comets and meteoroid showers are well known [39-40]. Substantial quantities of meteoric particles have been observed in the composition of many comets, which, becoming liberated from the heads of the comets, have replenished the total quantity of meteoric matter in the solar system. The concept of "contaminated ices" in comets (Whipple), which corresponds very closely to the theory of ices formed in volcanic regions of planetary bodies and mixed with particles of volcanic sand and ash, clarify the mechanism for the connection between comets and meteoroid showers.

However, investigations of the evolution of showers show that /128
they are depleted very rapidly. A great deal of data show that there are meteoroid showers which were not formed from comets, but which have only a common origin from a certain comet. Obviously, some

showers need not be related to comets at all.

The mere fact that showers can be observed indicates that they were formed relatively recently. Doubtless hundreds or even thousands of years were sufficient for complete expansion of the showers. Not only the planetary disturbances, but also the Poynting-Robertson effect and, what is more substantial, the bombardment of the surface of meteoric bodies by particles of solar corpuscular streams should bring about the dispersion and fragmentation of the particles of meteoroid showers [41]. Obviously, a theoretical estimate of the velocity of the process corresponds more or less to the evolutional velocity observed.

The motion of a meteoric particle in interplanetary space is determined not only by the attractive force of the Sun and planets disturbing its Kepler orbit, but also by the pressure of solar radiation in the Poynting-Robertson and Radziyevskiy effects, as well as the effect of corpuscular radiation and the magnetic fields transported by the magnetic fluxes and the total magnetic field of the solar system.

The effect of the radiation pressure can be estimated; particles of micron and sub-micron measurements are repelled by the effect of solar rays with an acceleration, depending on the dimensions and nature of the particles with this acceleration which should not exceed twice the acceleration of the solar attraction in order of magnitude. Particles of greater dimensions should be decelerated, and the preliminary orbits should just be altered. As a result of the Poynting-Robertson effect, the particles approach the Sun along a twisting spiral, and are evaporated and ejected from the solar system in the form of a gas flux. If the initial orbit of the particle is elliptical, the eccentricity will continuously decrease as its dimensions decrease.

Theory allows us to estimate the velocity of this process and use the calculations of V.G. Fesenkov.

For a particle with radius of ρ cm moving along a spherical orbit, the duration of the fall toward the Sun Δt from a distance of r_0 is equal to $6.5 \cdot 10^6 \, r_0^2$ years (if the density is assumed to be equal to 1 and r_0 is expressed in AU).

A particle with diameter of 0.02 cm, beginning to move around the Sun at a distance of 0.5 AU, should cease to exist after 2660 years. In moving along an extended orbit with $e > 0.9$, it should change its orbit radically in 100 years. The meteoric particles with orbits of small dimensions which have been observed photographically and with radar should be of very recent origin.

The elliptical meteoroid showers of the present, just as a huge mass of meteoric particles which have orbits mainly of a planetary nature, can be formed only as the result of the effect of /129

forces connected with planetary bodies. In this regard, it develops that the idea of the capture of the shower due to perturbations from large planets should be eliminated, since such perturbations should bring about the rapid diffusion of the particles in the shower.

Thus, the data on the rapid evolution of showers and on the predominating elliptical orbits with straight forward motion indicate that the meteoric particles could be formed as a result of the eruptive processes on planetary bodies.

The short-period showers which move in the central regions of the planetary system and which directly compel us to assume that there are high-energy processes of vulcanism on Venus and, perhaps, on Mercury and Mars, are of particular interest in this regard. An investigation of the photographic and radar orbits of meteors, of which many of have a small q and a, directly prove that they were formed recently in the solar system, apparently as the result of straight-line ejections from the surface of central planets of the Moon.

An investigation of the physical nature and chemical composition of meteorites leaves no doubt that they should represent fragments of the crust of planetary bodies. Many meteorites have been found to be similar to terretrial volcanic tuff in their structures [42]. Several years ago, this basic conclusion of meteoritics was considered an argument in favor of the hypothesis of the eruption of a single planet. However, data have recently been obtained which show that no less than 5 planetary bodies should have served as the source of meteorites. In this regard, the conclusion of the eruptive or volcanic nature of processes on planetary bodies is drawn, completely regardless of the conclusions of cometary astronomy.

The idea that meteorites are bodies of an asteroid nature and that asteroids can be examined as large meteoritic bodies is widely accepted.

An investigation of the physical nature and luminosity of asteroids shows their fragmentary form, while their connection with comets, which is expressed in the characteristics of motion and in the similarity in physical nature, allows us to conclude that comets should convert into asteroid or meteoritic bodies after their ice reserves are depleted. Actually, the present short-period comets differ from asteroids only because they have ice and they are of lesser masses.

In terms of the characteristics of their motion, comets should be younger formations on the average, characterized not only by rapid depletion of the ice reserves but also by an orbital shape less stable and farther from the circular. The eruptive processes /130 which give rise to the corresponding families of comets should also

occur at the present in the system of Jupiter satellites and in the Saturn, Uranus and Neptune systems. The existence of not only the short-period meteoroid showers but also of Comet Encke makes the possibility of recent eruptive activity on Venus probable.

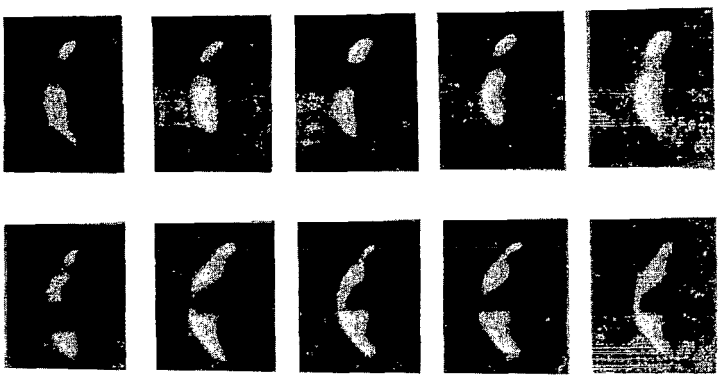

Fig. 37. Photographs of Venus in the Ultraviolet With Dark Spots, Which May be Regions Saturated With Particles of Ashes.

L. Schulhof [43] considered at one time the close convergences between orbits of periodic and long-period comets and the orbits of planets, among which the convergences with orbits of Venus and the Earth are particularly numerous and close. He made the remarkable statement that there is only a very small number of "parabolic" comets which do not approach any planetary orbits.

In this regard, we must discuss some of the principle facts which give an idea of the processes occurring on the surface of large planets and some satellites of the planets.

Mercury. Herschel observed flares on the surface of Mercury and spoke directly of volcanos existing on this planet. However, the difficulties in observing Mercury compelled the majority of astronomers to doubt this. Nevertheless, partial turbidity of some regions of the planets noted by the observer indicated that there could be volcanic activity in these regions. Lunar observations indicated that an atmosphere of carbon dioxide arose in single periods [44]. The probability of active vulcanism on Mercury increased substantially after the discovery of the actual period of rotation of the planet (59^d), which does not coincide with its return period. /131

Venus (Fig. 37). The existence of a large quantity of carbon dioxide in the upper layers of the Venusian atmosphere and the substantial quantity of dust in this atmosphere, as follows from thorough photometric investigations in recent years [45, 46], is an important factor. These observational data confirm the theory that the gas and dust in the upper atmosphere might be the result of high volcanic activity on the planets during the present. The carbon

dioxide may be the product of dissociation of heavier hydrocarbon compounds, ejected in large quantity during volcanic eruptions; the dust is formed by particles of volcanic ash and sand which are ejected, as occurs in terrestrial eruptions into the uppermost layers of the atmosphere. The high percentage of dust from particles of ashes and the development of a high-energy cloud cover as the result of the ionized particles and condensation centers constantly penetrating the atmosphere bring about the high reflectivity of the outer surface, which should lead to a substantial decrease in the intensity of the solar radiation approaching the solid surface. It may be assumed that conditions for a substantial cooling of the planet's surface and for an increase in the ice formation in individual regions arise in this case.

It is possible that the outbursts of radio-frequency emission which are observed on Venus could indicate that there are flare-ups in volcanic activity on the planet. The discovery of the high temperature of the Venus surface by radio astronomers is a striking confirmation of the conclusion that there is active vulcanism on Venus, a conclusion which we drew in 1954. Despite attempts at explaining this temperature in terms of ionospheric processes or the greenhouse effect, there is reason to consider it to be the consequence of a gigantic lava stream on the surface of the planet which arose 7,000-9,000 years ago. The recent observations by N. A. Kozyrev [47] also showed that there is active vulcanism on Venus.

Earth. The total number of "vesuvian" volcanos presently active on the Earth exceeds 450. During the last 200-300 years there have been repeated eruptions which reached cosmic forces, among which, in addition to the catastrophic eruptions of Vesuvius (1631 and 1806), we can also cite the eruptions of Sangay (1729) in Ecuador, Papandayang (1772) in Java, Osamayama (1783) in Japan, Temboro (1815) on the Sumbawa Island, Coseguina (1835) in Nicaragua and /1
the famous eruption of Krakatoa (1883). The total quantity of ash, pumice and slag ejected in the eruption of Temboro is estimated at 200-300 km^3; the rumble of immense eruptions was heard at a distance of 2000 km, and the layer of ash at a distance of 160 km had thickness of 60 cm; the energy of this eruption is measured by values of 10^{27}-10^{30} erg.

The gigantic explosion on August 27, 1883 destroyed the greater part of the island of Krakatoa, ejecting into the air no less than 13 km^3 of rocks, producing gigantic waves, and killing almost 40,000 people. The detonation wave in the air circled the globe several times and was recorded at all geophysical observatories. A special examination of this eruption, using apparatus of contemporary hydrodynamics, showed that a substantial percentage of the erupted masses should have had velocities greater than 8 km/sec and could have been ejected into interplanetary space [48].

However, even these processes of cosmic force cannot compare with those volcanic eruptions in the Quaternary and Tertiary Periods (Alpine and Carpathian Volcanoes, Caucasian Volcanic Center) or in the Jurassic and earlier periods (Crimean and Caucasian Centers) where strata of volcanic ashes bore into the ground. For example, in the Ukraine, near Zaporozh'ye, there has been found a deep stratum of dolomitized limestone up to 160 cm in the thickness, and in southern Moldavia up to 80 cm in thickness. Even these still very insufficient data indicate that the consequences of volcanic eruptions in the Quaternary and Tertiary Periods should have spread over the entire earth. Obviously, the decrease in surface temperature and formation of ice characteristic of the glacial period is related to these processes.

In 1936, A.P. Pavlov wrote the following on the role of vulcanism in the history of the Earth: "Now only the remaining insignificant manifestation of volcanic activity is observed on the Earth: previously, this activity was perhaps the most characteristic and almost general manifestation of life of the planets, as it was on the Moon in former times"[16].

The theory that the glacial periods, which according to geological data occurred from 600,000-570,000, 470,000-430,000, 230,000-180,000, 100,000-60,000 and 25,000-13,000 B.C., should have been related to great intensification of volcanic activity on the Earth seems to be very probable. During these periods, the Earth obviously could produce a large quantity of comets and meteorites and could eject masses of meteoritic matter into the space of the solar system. The celebrated mineralogist V.N. Lodochnikov confirmed in 1935 that ash (meteoric) matter could be ejected from the surface of the Earth into other space. [49].

The sources and mechanism of volcanic processes remain unexplained to date. /133 However, doubtless the immense quantities of natural gas (methane, butane) and liquid hydrocarbons (oil) detected in the surface layers of the Earth near regions of recent or past volcanic activity should have some relationship to them. The remarkable similarity in the chemism of the cometary ices and the composition of these terrestrial gases and liquid components of volcanic regions indicate that geologists and astronomers could conduct a combined investigation of these past processes which determined the characteristics of the geological history of our planet.

In this regard, we can also mention the problem of the formation of mountains, which was remained completely unexplained to the

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[16] Pavlov, A.P.: Geologicheskaya istoriya yevropeyskikh zemel' i morey (The Geological History of European Lands and Seas). Moscow, Acad. of Sci. U.S.S.R. Press., 1936, p. 87.

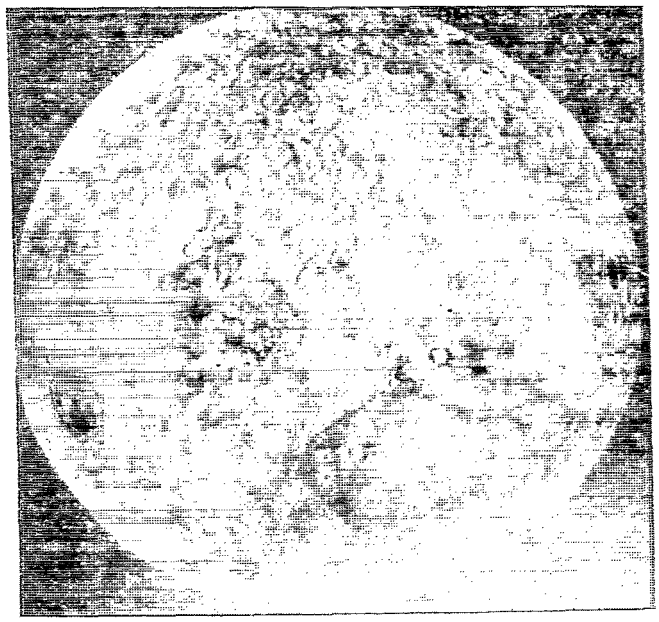


Fig. 38. Near Side of the Moon (Photograph Mounting Obtained at Lick Observatory in the First and Last Quarters).

Fig. 39. Crater Alphonsus with Central Mound from Which N.A. Kozyrev Observed the Eruption of Gases.

present. We cannot disregard the /134
fact that the youngest regions of mountains on the Earth are connected with regions of volcanic activity. If we compare the conclusions of cometary and meteoric astronomy relative to the nature, origin and scales of the eruptive processes on planets, then the following concept necessarily arises. The deformation of mountains may be the result of ejection of immense masses of gas in processes of a cosmic nature and the dispersion of solid and melted rocks from below the solid crust of the planet. The formation of hollows below the planetary crust should then bring about its deposition and crumbling, i.e., the arrival of mountain change, the development of high-energy tectonic phenomena. From this point of vies, the phenomena

of mountain formations and the release of the surface itself can serve as an indication of the nature and scales of volcanic processes which have occurred in the history of the planets and of our Earth. In view of this we should conclude that in the interiors of planetary bodies, for a rather large part of their history, processes took place which added to the enormous energy expenditures on periodically reappearing cosmic vulcanism. These could be physical-chemical processes leading to the formation if gases of processes of nuclear transformation completed by the release of atomic energy.

The Moon (Fig. 38). In recent years the data from terrestrial observations and special investigations of the structure of the lunar surface using the Lunik, Ranger and Surveyor spacecraft caused us to become more and more certain that we are observing the traces of powerful volcanic activity on the lunar surface (Fig. 39). We should place heavy emphasis on the discoveries of N.A. Kozyrev and V.S. Troitskiy [50]. The latter, on the basis of careful investigations of lunar radio emission, established the existence of /135 high temperatures and energy sources in its interior. This indicates that processes of catastrophic nature must have taken place on planetary bodies of lesser dimensions during particular periods of their development. The ejection of a body with a mass of 10^{12} - 10^{18} g (possible mass of comets and small asteroids) from the surface of the Moon or other similar satellites requires energy on the order of 10^{23} - 10^{29} erg. It is very interesting that from an examination of the dimensions of lunar craters and the heights of the ring mountains we estimate the energy required for their formation at 10^{25} - 10^{29} erg, i.e., we obtained an energy on the same order as that required for the formation of asteroidal and meteoric bodies.

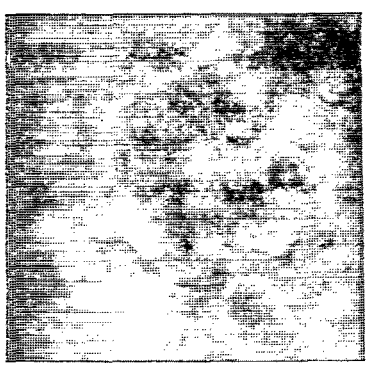


Fig. 40. A Portion of the Surface of Mars (a Region of the Mare Sirenum) with Craters, Transmitted on July 15, 1965 by the Interplanetary Spacecraft Mariner 4.

Mars (Fig. 40). We must note here the McLaughlin hypothesis [51] in relation to the volcanic nature of a number of details on Mars and also direct observations [52] which lend credibility to our conceptions of the significant development of vulcanism on this planet. In particular, observations made earlier and during the time of the great opposition in 1956 of the cloudiness of the planet's atmosphere and the yellow colored clouds are naturally attributed to volcanic phenomena on the surface since there is no serious reason (due to the thinness of the atmosphere and the lower level of solar radiation in comparison with the Earth) to

attribute these phenomena to dust storms.

Photographic investigation of the martian surface, made using the interplanetary probe Mariner 4, showed that there are cirques on the planet similar to those on the Moon. This is direct evidence of the decisive role of vulcanism, if not in the present, then at least in the planet's past.

Jupiter. In the nineteenth and early twentieth centuries great popularity was enjoyed by the notion that processes of vast catastrophic nature took place on the surface of this planet beneath its heavy atmosphere. In particular, the red spot was seen as a region of an immense sea of lava, which was sometimes covered by a thick layer of clouds [53]. A. Crommelin saw in these rapid changes on the disk of the planet one of the most important arguments in /136
favor of the disruption theory. Subsequently, a new theory of cold planets covered with an immense layer of ice changed the minds of some investigators. Nonetheless, a direct detailed study of the phenomena on the surface of Jupiter in recent years as well as the development of the theory of the internal structure of the giant planets caused a return to the notion of powerful processes on its surface. As important substantiation of this conclusion we can point to the enormouse increase activity on the surface of Jupiter in 1961-1965. As evidence of the catastrophic nature of the processes which take place on the surface of Jupiter, we can point to the high dust content in the upper layers of its atmosphere and the very high observed burst of radio emission, related to particular activity regions.

The conclusions of small body astronomy has forced us to turn our undivided attention to the study of the eruptive processes on the planets and primarily in the Jupiter system. In Kiev in 1950, systematic photographic and visual observations of the surface of Jupiter were begun.

At the beginning of the 1960's the Greek astronomer Focas, based on an analysis of numerous drawings and photographs of Jupiter over more than a hundred years, reached the conclusion that there was a cyclic change in the state of activity on this planet. The initial stage of this activity has a cataclysmic character. Bright white spots and groups of these spots appeared at this stage usually near the dark bands. Then dark node appeared which, as a rule, followed the bright spots. From these spots, dark filament flares erupted moving in the direction opposite the rotation of the planet. The development of these flares leads to the appearance of stable, very dark bands; this marks the activity maximum. After maximum the belts or bands slowly deteriorate, becoming lighter and wider, as if seen through a semitransparent medium of constantly increasing thickness. Apparently the dark matter of the bands sinks. Activity minima occur when an overall brightening of the planet's surface is observed. This comes every 20 - 22 years.

Focas proposed that 1961 would be the year of approach to activity minimum on Jupiter. However, the development of the processes on the planet disproved his prediction.

In 1960 and 1961 Jupiter stood very low in the sky and was almost inaccessible to observations in the northern hemisphere. But observations were continuously made in Japan and drawings made by members of the Jupiter section of the Eastern Astronomical Association (under the leadership of Takeshi Sato, Hiroshima), together with other data allowed them to determine the evolution of these phenomena.

In 1960 the northern tropical band was especially active; the /137
red spot, after its disappearance in 1959, again showed its bright red color. The southern tropical band descended almost to the equator, but the equatorial zone was bright and almost clear. In 1961 we noticed an even higher degree of activity in the equatorial zone and a hazing over of its bright regions. A complete change in the appearance of the planet apparently took place in August 1961, when a very dark, wide equatorial band formed (cf. Fig. 41) (this repeated the transformation of 1872-1878).

It was established from an analysis of bursts of radio emission from Jupiter, which have been recorded for more than ten years, that precisely in 1961 a drastic change took place in the rotation velocity of the most powerful source of bursts of radio emission on the planet.

During 1962-1964, when Jupiter was in a more favorable position for northern observations, astronomers noted an unusual activity first in the southern hemisphere of the planet then in the northern hemisphere. Drastic changes took place even over a few days, which indicated the enormous power of the cataclysms taking place on the planet.

As a result of the flare of 1961 the overall brightness of the planet decreased significantly. Measurements made first at Kiev and then at other observatories showed that the brightness of the planet decreased by a factor of almost 1.4. This allowed us to compute the reflectivity (albedo) of the matter of which the dark, dense equatorial band is formed: the albedo was very small (as it is for terrestrial volcanic ash). We were even able to estimate the total quantity of volcanic ash ejected higher than the usual cloud level. We obtained the value $10^{21} - 10^{22}$ g, i.e., millions of billions of tons. This value, though only an approximation, characterizes the possible force of the cataclysms on this giant planet [54].

We can also fully understand the sometimes nonuniform rotation of the red spot which many considered evidence for the hypothesis of its atmospheric nature. Apparently, the comparatively thin, dark crust of the planet has numerous breaks along the parallels

which characterize the highest degree of volcanic activity. It is wholly possible with massive processes on Jupiter that zones, rotating at different angular velocities, converge and diverge.

Astronomers measured the brightness of Jupiter for more than a hundred years. In certain periods (in particular the 1870's and 1880's) a decrease in brightness was observed of almost one and a half times compared to the normal brightness; but no attention was given to this fact. Now it has become obvious that measurements of the brightness of Jupiter allow us to record the development of the volcanic processes on its surface. Matter, thrown during disruptions to the upper layers of the atmosphere, returns to the surface of the planet; due to the enormous mass of Jupiter and the /13
strong force of gravity, only particles having velocities on the

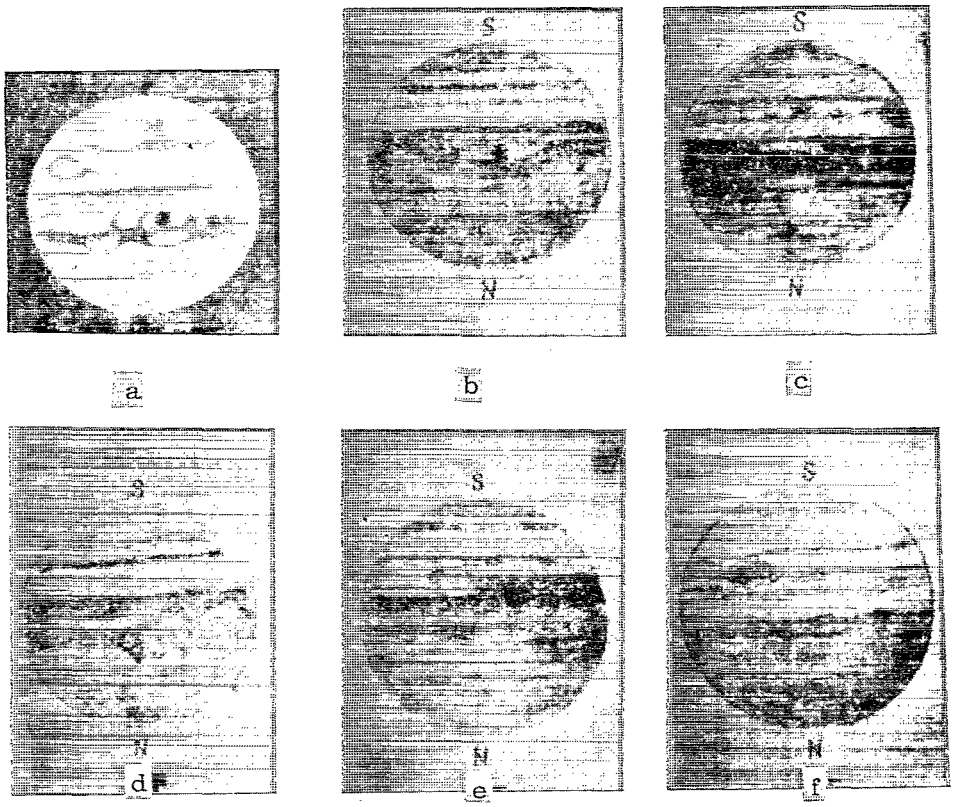


Fig. 41. The Cataclysm of 1961-1965 on Jupiter and the Ash Belts of the Planet: (a) Drawing by Takeshi Sato (Hiroshima) on July 12, 1960; (b-f) Drawings by S. Vsekhsvyatskiy on, Respectively: October 7, 1962, November 4, 1961, January 23, 1964, October 28, 1964, September 23, 1965.

order of 48 - 60 km/sec can be thrown from the sphere of attraction. Evidently, only a negligibly small portion of the disrupted matter can have such enormous velocities. The ejected matter returns to

the surface and the planet undergoes practically no loss of matter.

The situation is entirely different on the moons of Jupiter.

The Moons of Jupiter. The existence of short-period comets indicates that there is explosive volcanic activity on moons. In order to eject the masses of ash particles or fragments of the crust into nearby space, a velocity of 1 - 3 km/sec is sufficient (i.e., /139 ten times less than on Jupiter). Is there any evidence of such flares?.

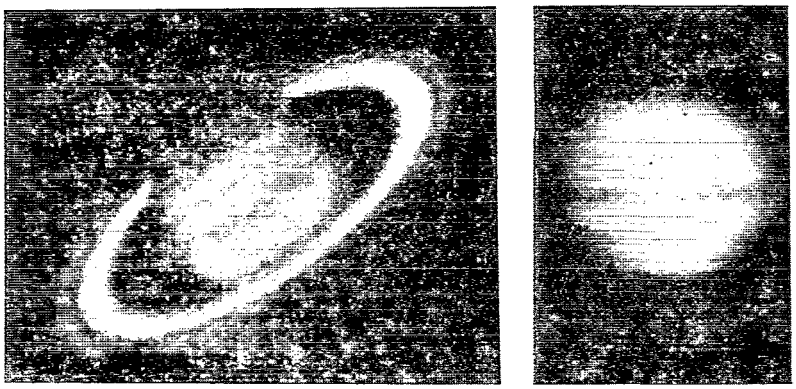
Experimental observations with the largest telescopes noted on the disks of these "planetoids" white spots and various changes, but such observations are difficult and cannot be confirmed. Much more important was the discovery in the 1940's of gaseous atmospheres on Titan and Triton. At such an enormous distance from the Sun, the existence of nonfrozen gaseous atmospheres should be attributed either to volcanic disruptions, which carry masses of gas up from under the crust of the moons, or to the appearance of a hot region (sea of lava) which evaporates the frozen atmosphere and heats the gases. Other explanations are impossible since no gaseous atmosphere was detected on the Galilean moons at that time, although thermal action on them from the Sun was several times stronger. The high values of the albedo and special observations in the infrared range substantiated the fact that Titan and Triton were covered with ice and therefore might actually produce comets. For a period of almost 80 years observers of Jupiter noted on the disk of the planet a thin equatorial band which would disappear and then reappear. Studies showed that this band might be the shadow of a thin ring encircling the planet and similar to the ring of Saturn [55]. However, a lasting ring is possible only if matter is constantly added to the ring during disruptions on Jupiter's moons.

Very recently we obtained new evidence of activity in the Jupiter system. Astronomers at the Pulkov observatory detected gaseous atmospheres on the Galilean moons which would disappear and then reappear. In addition, a relationship was discovered between the period of rotation of Io and cyclical changes in radio emission from Jupiter.

Saturn (Fig. 42). One of the disruption theory's conclusions is the existence around certain planets of meteor-dust or cometary clouds, which must be replenished due to ejections at velocities lying between circular and parabolic limits (first and second cosmic velocities).

Even in 1952 the argument was proposed that Saturn's ring must be such a cloud. The eruptive origin of Saturn's ring was also indicated by the existence of high degree of activity on the surface of the planet ("white spots" were observed in 1876, 1891, 1933, 1949) and the blue (in comparison to the planet) color of the ring (the presence of gas and ice), and significant changes in the rings,

noted throughout the history of astronomy. These changes were pointed out by Trouvelot in 1884. In 1907 Fournier and independently in 1908 Scherr detected the appearance of a weak outer ring which at the beginning of 1909 could still be seen by the Greenwich astronomers. Later the ring disappeared. Something similar was /140
again observed in 1952-1953. At the moment when the Sun passed through the plane of the ring, with its disappearance, clusters were observed in 1907-1908 and in 1921. We should not ignore a fact like



a b

Fig. 42. Photographs of Saturn: (a) with Ring Exposed; (b) at a Moment When the Earth Is in the Plane of the Ring.

the observation by Barnard in 1908-1909 of a solid ring of unusual brightness. It is natural to explain all these changes in the rings of Saturn by new additions of the products of volcanic disruptions taking place both on the moons of Saturn and on the planet itself and by the rapid evolution of the matter in the rings as a result of collisions and resistence to the motion of the component rings.

No less important for an understanding of the nature and origin of the ring are the possible systematic changes in the ring's width and distance from the limb. This was first noticed by Otto Struve in 1852.

Based on the data of Otto Struve and the data of observations from 1883 to 1943, S.K. Vsekhsvyatskiy found that over 300 years the mean line of the bright rings moved closer to the surface of the planet by approximately ten thousand kilometers. This provided an opportunity to estimate how much energy (3.10^{36} erg) is expended by the ring matter on collisions and pulverization and on thermal dissociation; under certain conditions we can find the gas concentration in the area of the ring (10^2 - 10^3 molecules per cm^3).

Apparently, we should consider as fact the inward expansion of the ring and the approach of the inner sections to the planet, while the distance of the outer rings remains almost constant. This process must also take place as a result of collisions of the par-

ticles of the ring when the total energy decreases since it is /141
expended on disintegration and heating.

These results and the very existence of a flat ring independently indicate the replenishing of ring material, a process which is taking place even at the present time, and, consequently, powerful flares from the surface of the planet and its moons at a period significantly later than the time of formation of the planet.

Saturn's Moons. All the moons closest to the planet have a high albedo which allows us to assume the existence of ice covers. The surge of matter from the surfaces of Mimas, Enceladus, Tethys, Dione and Rhea can occur at very low initial velocities (on the order of several tens of kilometers per second). However, disruptions will take place only if sources of the necessary energy are preserved inside these moons, i.e., if enough heat is maintained in the deep regions to support the physical-chemical processes.

In connection with this argument, the discovery of a gaseous atmosphere on Titan is of special importance. The explanation that its existence is due to a weakening of the dissociation and solar interaction processes, as was proposed by J. Kuiper, cannot be accepted since the atmosphere would have frozen if only by significant temperature inversions. Therefore, it is necessary to assume the existence of a heat flux, i.e., a sufficient heating of the moon's hard surface to support the gaseous state of the atmosphere.

Uranus. Despite the significant distance of the planet and the absence of a constant situation on its surface, the appearance of powerful activity was also observed on Uranus. In the light of data characterizing the history of the Earth and the Saturn system, the peculiarities of the contemporary rotation of the Uranus system can be attributed to gigantic cataclysms which changed the initial conditions on the planet.

Neptune and Pluto. The existing observational data regarding Triton allow us to draw a parallel between the characteristics of the Neptune system and the Saturn system. Kuiper's opinion, which is shared by many other astronomers, that Pluto may have broken away from Neptune indicates the necessity, in all seriousness, of studying the past of the planets bearing in mind the definite role of catastrophic processes.

The indicated facts and new arguments are interesting and valuable both for an understanding of the actual history of the planets and for the solution of the many other problems of the solar system. It is becoming more and more clear that the independently examined problems of the planets, planetary moons, meteoric matter, comets, cosmic (meteoric) dust, the problems of our Moon must be studied simultaneously since they present different facets /142
of the possible dynamic processes which have taken place and are

taking place in the solar system.

A study of planetary activity and vulcanism must be one of the central tasks of the astronomy of the solar system. To this study are linked not only the possibility of clarifying the actual history of the planets and the solar system as a whole but also the solution to practical problems of geology and geophysics.

Undoubtedly the data of planetary investigation presents special opportunities both for the theory of the structure of the Earth and also for biology and other Earth sciences. A special role in the checking and substantiating of our picture of the actual processes in the solar system belongs to interplanetary spacecraft and other means of extra-atmospheric astronomy.

20. An Estimate of the Number of Comets Formed in the Solar System

The question of the number of comets is of great importance since it allows us to clarify the actual scales of comet formation and the role of comets in the cosmogonous process.

The number of comets in Oort's cloud, according to his estimate, is $1.9 \cdot 10^{11}$, and the total mass is on the order of $2 \cdot 10^{27}$ g. However, Oort began from a system of conditions which assumed an increase in the number of comets toward the boundary of the solar system.

We will estimate the number of comets beginning from other, less conditional assumptions. We will assume that the annual mean number of new discoveries of almost parabolic comets characterizes a steady state in the solar system over the last several tens or hundreds of millions of years.

For the last 45 years the number of new "parabolic" comets has reached 102, and for long period comets ($500 < P < 20{,}000$ years) the number is 32. On the average more than 2 parabolic comets approach the Sun every year, included in the sphere of sight. We have every reason to assume that the number of comets of a single type (in relation to their absolute magnitude H_{10}) increases in proportion to the perihelion distance and even to some degree: q^t ($t > 1$); therefore within the limits of the planetary system (up to 45 AU) over the course of one year ten times more comets than are included in the sphere of sight may pass through perihelion. We will take as a minimum number 20 - 30.

Furthermore it is necessary to estimate the number of comets which remain unknown due to an unfavorable position in the sky or other reasons, in particular low brightness. Starting from the distribution of the absolute magnitudes of comets and taking into account the probability of discovering a comet, we can obtain the following revised distributions of n' (cf. Table 19).

TABLE 19

H_{10}	−2	0 — 2	2 — 4	4 — 6	6 — 8	8 — 10	10 — 12	12 — 14
n	2	6	26	92	119	57	23	4
n'	2	6	26	171	450	3360	6000	8000

Thus if we wish to take into account all comets up to $H_{10} = 14^m$, we must increase the number of comets which pass annually through perihelion by the ratio $\frac{\Sigma n'}{\Sigma n} = \frac{18015}{329} \approx 50$.

Consequently, with a steady state for the time of existence of planetary bodies ($4 \cdot 10^9$ years), we obtain the total number of comets $N = 2 \cdot (20\text{-}30) \cdot 50 \cdot 10^9 \approx 10^{12}$.

Here we have estimated the total number of comets which have returned to the Sun, into the central regions of the solar system, from the boundaries of the sphere of solar activity, after completing one or more revolutions after the origin of the planets in the system. However, the number of comets ejected during volcanic disruptions on the planets and moons, of course, cannot be limited only to parabolas. There must be a greater number of ellipses of smaller dimensions or hyperbolic and sharply hyperbolic orbits. This follows directly from an examination of the eccentricity distribution of the orbits for comets with different values of P. (cf. Fig. 4).

All comets formed in the region of planets and having hyperbolic velocities escaped to interstellar space; the process of ejecting comets from the solar system continues as a result of the action of planetary disturbances, which change the motion of almost parabolic and elliptical comets. Ejection as a result of disturbances is one of the mechanisms which decreases the number of comets having elliptical orbits. However, the main reason which explains the present small number of comets with average periods (from several tens of years to tens of thousands of years) should be assumed to be the depletion of cometary gases, the sublimation of cometary ices by the action of solar photon or corpuscular radiation. As can be seen in the example of short-period and periodic comets, several tens of passages through perihelion (of course, in the case q < 3-5 AU) can lead to the depletion of cometary gas material.

Thus parabolic comets must comprise only a small fraction of the comets having elliptical and parabolic orbits.

If we assume a spherical velocity distribution in a certain initial state, then in the velocity space the number of almost "parabolic" comets can be estimated by the volume of a spherical layer of thickness dv. We will take the function for the distribution of velocity values in Oort's form: $f(v) = 3L^{-3}v^2$, when $L > v$ /144 and $L = 3\frac{\sqrt{2}}{\sqrt{D}}$ (i.e., triple parabolic velocity).

In this case the number of initial "parabolic" comets will be:

$$P = 4\pi v_0^2 f(v_0)\,\Delta v = 4\pi v_0^2 f(v_0)\,\frac{\Delta a}{2a^2\sqrt{\frac{2}{D}-\frac{1}{a}}} = \\ = 4\pi\frac{2}{D}\cdot\frac{\sqrt{D}}{3^2\sqrt{2}}\cdot\frac{\Delta a}{2a^2\sqrt{\frac{2}{D}-\frac{1}{a}}}. \tag{105}$$

According to Oort's assumption, $a \approx 100{,}000$ AU, and we can also assume that $\Delta a \approx 100{,}000$ AU.

It is obvious that the number of elliptical and hyperbolic comets, respectively, will be

$$E = 4\pi\int_0^{\sqrt{\frac{2}{D}}} v^2\cdot 3L^{-3}v^2\,dv \tag{106}$$

and

$$H = 4\pi\int_0^{\infty} 3v^2L^{-3}v^2\,dv. \tag{107}$$

After integrating, we obtain the relative number of elliptical and hyperbolic comets:

$$\frac{E}{P} = \frac{4{,}2\cdot 10^4}{D};\quad \frac{H}{P} = \frac{3{,}5\cdot 10^6}{D}, \tag{108}$$

where D is the radius of the orbit (by assumption, circular) of the generating planet.

We obtain the same order of magnitude for the ratio of the numbers of comets with another initial velocity distribution. For example, assuming an equally dense distribution of the end points of the vectors in our initial scheme (this distribution is the most favorable for Oort's idea since he assumes a significant increase in the number of flares with parabolic velocities), we come to the following problem (Fig. 43).

The figure shows in the correct scale the conditions for the planet Neptune. The center at point P corresponds to the distribution of relative velocities while the circles correspond to spherical distributions with a maximum initial velocity on the surface of Triton of 6 and 12 km/sec. Point O is the center of the distribution of heliocentric velocities, and the circle divides elliptical

and hyperbolic velocities; the radius of the circle is equal to $\sqrt{2/D}$, $OP = 1/\sqrt{D}$; the maximum values of the relative velocities are denoted by V_ρ.

Assuming in the simplest case a uniform density of vector end points in the velocity region we can see that the relative numbers of elliptical and hyperbolic comets will be proportional to the volumes of the regions $ACBD$ and AEB, described by spherical surfaces with centers at O and P. The density equation in which the circle which is the result of the intersection of the maximum spherical surfaces lies is as follows:

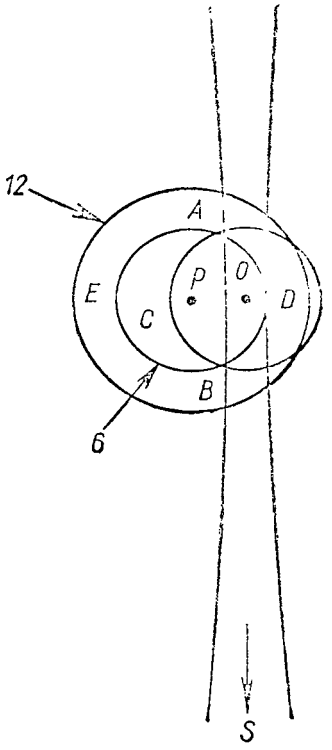


Fig. 43. Elliptical and Hyperbolic Comets of Neptune.

$$y = \frac{3}{2}D^{-\frac{1}{2}} - \frac{1}{2}V_\rho^2 D^{\frac{1}{2}} \qquad (109)$$

(the y axis lies in the direction of the motion of the planet; the x axis lies in the direction of the radius vector).

The distance between the plane in which the boundary line of the two spheres lies and point P is $F = \frac{V_\rho^2 D - 1}{2\sqrt{D}}$. Then for our particular case the volume of the region of ellipses will be determined as follows:

$$E_{ACBD} = \frac{1}{3}\pi\left[(V_\rho - F)^2(2V_\rho + F) + \left(\frac{\sqrt{2}-1}{\sqrt{D}} + F\right)\left(\frac{2\sqrt{2}+\frac{3}{2}}{\sqrt{D}} - \frac{V_\rho^2\sqrt{3}}{2}\right)\right]. \qquad (110)$$

Analogously, we can obtain an expression for the volume of the region of hyperbolas:

$$H_{AEB} = \frac{1}{3}\pi\left[4V_\rho^3 - (V_\rho - F)^2(2V_\rho - F) - \left(\frac{\sqrt{2}-1}{\sqrt{D}} + F\right)^2 M\right] \qquad (111)$$

(M denotes the expression: $\frac{2\sqrt{2}+\frac{3}{2}}{\sqrt{D}} - \frac{V_\rho^2\sqrt{3}}{2}$).

The relative number of parabolic comets is determined, obviously, by the volume of a thin spherical layer ACB, which we can find by computing the product of the plane of the side surface of spherical /146

segment S ($S = \sqrt{2\pi}\,\frac{2\sqrt{2}-3}{D} + V^2_\rho$) and the height of the layer corresponding to those bounds of the values of semiaxis a which yield parabolic comets. Then the ratio of the total number of elliptical comets to the total number of parabolic comets will be equal to

$$\frac{E}{P} = \frac{a^2\sqrt{2}}{3\Delta a} \cdot \frac{\sqrt{\frac{2}{D}-\frac{1}{a}}}{\left(\frac{2\sqrt{2}-3}{D}+V_\rho^2\right)}\left[(V_\rho - F)^2(2V_\rho + F) + \left(\frac{\sqrt{2}-1}{\sqrt{D}}+F\right)M\right], \tag{112}$$

and the relative number of hyperbolas will be

$$\frac{G}{P} = \frac{a^2\sqrt{2}}{3\Delta a} \cdot \frac{\sqrt{\frac{2}{D}-\frac{1}{a}}}{\left(\frac{2\sqrt{2}-3}{D}+V_\rho^2\right)}\left[4V_\rho^3 - (V_\rho - F)^2(2V_\rho - F) - \left(\frac{\sqrt{2}-1}{\sqrt{D}}+F\right)M\right]. \tag{113}$$

For those values of a and Δa which we took earlier, for the Jupiter system ΔV will have the value $\frac{3}{4}\,10^{-5}$, and for the Neptune system ΔV will have the value $2\cdot10^{-5}$.

Assuming a limiting value $V_\rho = 0.5$, we find that $\frac{E}{P} = 6\cdot10^4$; $\frac{H}{P} = 2\cdot10^4$ for the Jupiter system and $\frac{E}{P} = 1.2\cdot10^4$; $\frac{H}{P} = 9.6\cdot10^3$ for the Neptune system.

Under special assumptions concerning the function of the distribution of velocity vectors, we can find small values for $\frac{E}{P}$, but in this case the value of $\frac{H}{P}$ will be on the order of 10^3 - 10^4. On the other hand, with small values of $\frac{H}{P}$ the number of ellipses will be predominant. Thus with any rational assumptions about the system of flares the number of initial elliptical or hyperbolic comets must be 3-4 orders of magnitude greater than the number of parabolas.

Consequently, beginning from a total number of parabolic comets /147 formed in the solar system during its existence (10^{11} - 10^{12} years), we obtain a total number of comets ejected from the surfaces of planetary bodies $N = 10^{11}\cdot(9.6\cdot10^3 - 6\cdot10^4) \approx 10^{15}$.

The number of comets with an initial mean absolute magnitude $H_{10} = 11^m - 12^m$ must have been on this order of magnitude.

The mass of comets of such brightness may be, according to estimates, about 10^{14}- 10^{15} g, which yields for the total aggregrate mass of flares from the surfaces of planetary bodies, including ice (frozen gases of planetary atmospheres), the following values:

$$\sum M \approx 10^{15} \cdot (10^{14} - 10^{15}) \approx 10^{29} - 10^{30} \text{ (g)}.$$

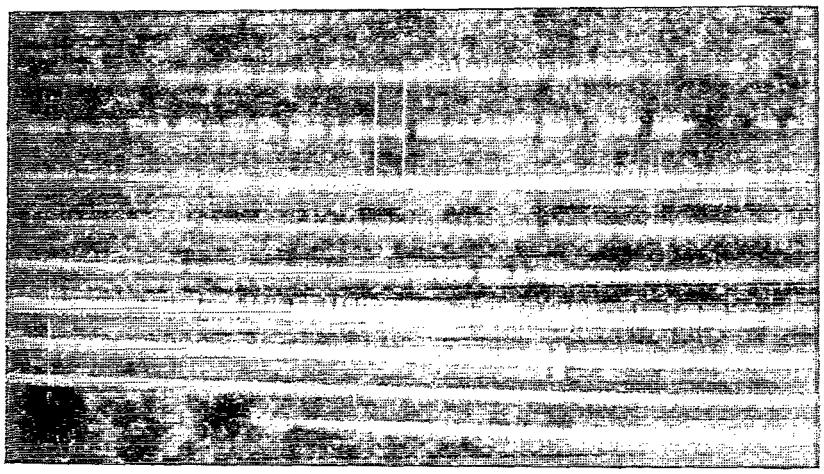
These calculations show that comets could scarcely have originated as a result of the explosion of only one planet (Phaethon), to which formation of the system of asteroids and meteoric masses is related.

The high value of the aggregate mass of comets (and, consequently, of meteoric matter) can be understood only from the point of view of disruption theory. The ejection of matter by the planets in the form of ice, ash particles (meteoric dust) and other dispersed material in the form of fragments of the crust of the planet is an important cosmogonous factor. The characteristics of distribution of comets with a maximum number near the parabolic limits indicates that we are observing basically the first returns to the Sun of the almost parabolic comets formed in the system of planets.

We must emphasize that our estimates require more precision. The assumption which we made concerning the stationarity of the processes of comet formation in reality is not valid. A study of the geological history of the Earth indicates the existence of periods of high volcanic activity interspersed by periods of relative calm. We observe the same periodicity in other cosmic and geophysical processes where this phenomenon is related to the gradual building up of the forces which cause flares and to the rapid occurrence of cataclysms.

21. Additional Proof of the Eruptive Origin of Comets and Meteoric Matter; New Problems

We also noted new facts and recent discoveries which can substantiate and prove the validity of the assumptions of the disruption theory. We refer to: (a) a possible flare of volcanic activity in the Jupiter system (1961-1965) and the related appearance of the comets Kerns-Kwi and Su Chin Shan I and II; (b) the increasing certainty of a high degree of vulcanism on the Moon, Venus and Mars; (c) observation of the comet Ikeya-Seki 1965f (Figs. 44, 45) which proves the presence of meteoric masses in the nuclei of comets and consequently their planetary origin; (d) the cometary nature of meteor showers and sporadic meteors which move in the central regions of the solar system; (e) the groundlessness of Oort's idea of a cometary cloud; the increasingly obvious inadmissibility of wide-



/148

Fig. 44. The Spectrum of the Comet Ikeya-Seki 1965f for the Period of Its Passage Through Perihelion. The Spectrum Was Obtained Using the Coronagraph of the Sacramento Peak Observatory (USA). We Can See the Emission of Iron, Nickel, Chromium, Sodium, Potassium and Other Elements Which Prove the Presence of Meteoric Masses in the Nucleus of the Comet.

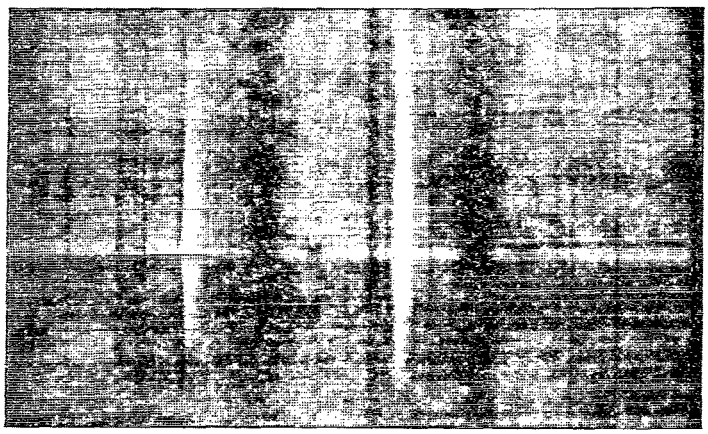


Fig. 45. D_1 and D_2 Sodium Emission in the Heat of the Ikeya-Seki Comet; the Spectrum Was Obtained Using the Large Solar Telescope at the Kitt-Peak Observatory (USA).

spread hypotheses (Kuiper, Whipple, Oort) concerning the origin of /149
comets which are easily disproved by comparison with the data of cometary astronomy. There is no place for these hypotheses in the area of the cosmogony of small bodies. In the present section we deal from a new point of view with the problems which elucidate the various aspects of the disruption concept.

We have already dealt with the character of the inclination distribution for the group of almost parabolic comets with P = 550 - 20,000 years and P > 20,000 years (cf. Fig. 4). Here we can clearly

see the existance of a maximum near i = 90° with almost total symmetry for direct and retrograde motions. The number of comets with i = 0 - 20° and 160 - 180° is approximately 40-50% of the number of comets for the interval i = 80 - 100°, but almost parabolic comets which originate in the region of the planets and return to the Sun from the boundaries of the solar system must also show this distribution character.

On the other hand, the anomalies in the inclination distribution (for example, minima at i = 100 - 120°) can be used to study the effect of the comparatively recent passages of stars in the far regions of the solar system.

We have the examined the characteristics of cometary orbits with P > 1000 years with i within the limits 100 - 120°. In our catalog there are 74 of these comets. The distribution of aphelion directions on the ecliptic sphere (Fig. 46) showed an insignificant number of them in the southern hemisphere and in addition a noticeable absence of points of exit of comets (aphelion direction) from the regions of the sky with coordinates:

$$\lambda = 340°;\quad \beta = -20° - 40°\ (\alpha = 20^h,7 - 23^h,0;\ \delta = +30° - 30°);$$
$$\lambda = 20°;\quad \beta = -30°\quad (\alpha = 2^h - 3^h;\quad \delta = -20°);$$
$$\lambda = 190° - 210°;\quad \beta = +40°\quad (\alpha = 13^h,6 - 15^h;\quad \delta = +25° - 18°).$$

The visibility conditions, probably, could not have played a significant role in the formation of these lacunae, since the distribution by the value $L - \lambda_0 \pm 180° = \psi$ (here L is the time of passage through perihelion expressed in longitude of the Earth and λ_0 is the perihelion longitude of the comet) does not yield a significant aggregate at small values of ψ.

The distribution of the 74 comets by ψ is as follows: 12 comets were at 0 - 30°; 10 comets were at 30-60°; 15 comets were at 60 - 90°; 9 comets were at 90 - 120°; 14 comets at 120 - 150°; 14 comets were at 150 - 180°. /150

Therefore we have every reason to explain the absence of comets from the indicated directions by the influence of comparatively recent perturbations from stars passing through the sphere of action of the Sun (in the peripheral regions of the solar system) near these directions.

Using the list of S.G. Makover we can even name the probable stars whose action may have transformed the orbits of no less than 50 comets which have not returned to the region of visibility, i.e., to the region of the planetary system where they were formed.

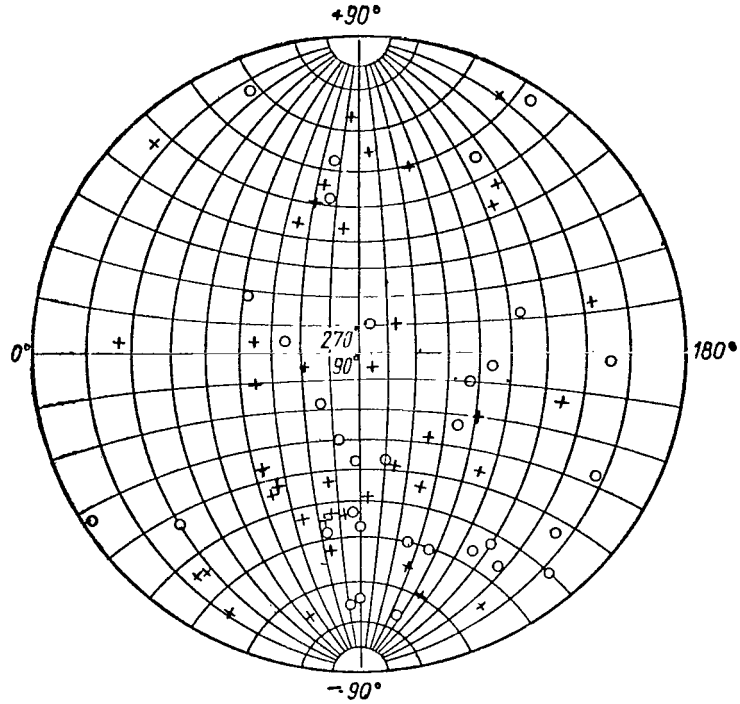


Fig. 46. The Distribution of Aphelion Directions of Near Parabolic Comets (i = 100-120°) on the Heliocentric Ecliptic Sphere ("+" Shows Longitudes from 0 to 180°; "○" Shows Longitudes from 180 to 360°).

The possible stars are in the first group μ and χ*For* (Formax); in the second group ζ*Boo* (Bootes), γ*Ser* (Serpens) and the star + 15°2620; in the third group ψ*Cap* (Capricornus) and α*PsA* (Piscis Austrialis).

In all three cases we can, apparently, indicate the star which /151 exerted the basic influence on distant comets: these are μ*For* in the first group, which approached closer to the Sun than any other star; ζ*Boo* and γ*Ser* which are the most massive of the stars in the second group; ψ*Cap* and α*PsA* (the third group) which are massive and correspond most in terms of time and the shortest distance during conversion.

The comparison which we have made indicates that under the influence of neighboring stars many of the almost parabolic comets only exit from the region of visibility.

The approach of short-period comets to the Jupiter system. We noted earlier that the closest approach of a short-period comet to a planet usually took place 1/2 or 1-1/2 revolutions before discovery; from an examination of 18 comets we found a relationship between the disintegration rate ΔH and the value of the least distance between the orbits of the comets and Jupiter.

This underscored the importance of the problem of convergences, although there was an obvious difficulty related to the vagueness of the reverse extrapolation based on changing initial elements. These variations must have been particularly great in the first period after the origin of the comet which was physically unstable and had not yet entered a stable orbit. The practice of ephemeresis survey shows that the error in the position of comets extrapolated for the next appearance is only in rare cases a few hundreds of an astronomical unit and is usually significantly greater. Only for old short-period comets which have already attained physical stability does long-range extrapolation yield more reliable results as is indicated by the outstanding discoveries of recent years based on the calculations of Marsden, Shubert and others (the comets Holmes, De Vico-Swift, Tempel-Tuttle).

We know of no less than 30 cases of close convergences since the middle of the 18th century, some of which have been studied with the necessary care. The most recent survey of the investigations of convergences of short-period comets with Jupiter is the well-known research of Ye. I. Kazimirchak-Polonskiy [56], who adds new data to the survey of the monograph of K. D. Pokrovskiy. We used this reference as well as others to compile Table 20.

The table shows that the comet Faye had not yet completed more than 4 orbits before its discovery since it had a high absolute brightness; apparently not earlier than 1816 the comet must have emerged from proximity with the orbit of Jupiter. The comets Helfenzrieder, Lexell, Brorsen, Wolf I, Brooks II, Schwassmann-Wachmann II, Whipple, Oterma, Ashbrook-Jackson, Shayne-Sheldeck must have been even "younger".

TABLE 20 /152

Discoverer and Name of Comet		Date of Convergence		Least Distance Δ	Absolute Magnitude H_{10}	Name of Mathematician
Helfenzrieder	1766 II	11/XI	1763	0,031	6,8	Wirtz
Lexell	1770 I		1767	0,022	7,7	Buchart
Pons-Winnecke	1819 III	II	1811	0,020	8,8	d'Arrest
Blanpain-Pons	1819 IV		1817	0,028	8,5	
Faye	1843 III	5/III	1841	0,63	4,2	
		III	1816	0,3		
De Vico-Swift	1844 I		1814		8,0	
Brorsen	1846 III	27/V	1842	0,051	7,2	d'Arrest
Tempel-Swift	1869 III	VIII	1840	1,02	11,4	Bothe
Crommelin	1873 VII	II	1841	0,18	11,6	Schulhof
Wolf I-Kamenskiy	1884 III	8/VII	1875	0,12	6,2	Kamenskiy
				0,08		
Finlay	1886 VII		1839	0,29	9,2	Faye
			1851	0,10		
		II	1862	0,41		Schulhof

TABLE 20 (cont.)

Discoverer and Name of Comet		Date of Convergence		Least Distance Δ	Absolute Magnitude H_{10}	Name of Mathematician
Brooks II	1889 V	20/VII	1886	0,0009	7,2	Castel
Barnard	1892 V		1875		9,8	Heinz
Denning	1894 I	16-23/II	1881		10,4	Schulhof
Swift	1896 II	18/II	1886	0,20	11,4	Schulhof
Perrine	1896 VII		1888	0,2	9,9	Berberich
Giacobini-Zinner	1900 III	30/X	1898	0,2	10,8	Yevdokimov
Daniel	1909 VI	II	1906			Cripps
Taylor	1916 I	II	1912			Jeffers
Comas-Sola	1927 III	17/V	1912	0,19	9,0	Ramenskiy
Gale	1927 VI	VIII	1917	0,1	9,5	Winter-Hansen Innes
Reinmuth I	1928 I		1925			Burman, Whipple
Schwassmann-Wachmann II		26/III	1926	0,18	8,0	Rasmussen
Forbes	1929 II	1907 —	1908			Crommelin
Whipple	1933 V	VI	1922	0,26	8,0	Tomas
Oterma	1942 VII	23/IX (VI?)	1937	0,17	7,8	Fokin
Reinmuth II	1947 VII	1943 —	1945	?	10,9	Cunningham
Ashbrook-Jackson	1948 IX	22/VI	1945	0,18	7,8	Merzlyakova
Honda-Mrkos-Pajdusakova	1948 XII		1935		12	Merton
Johnson	1949 II	1931 —	1932			Jackson
Shayne-Sheldeck	1949 VI	29/IV	1946	0,18	7,6	Dubyago
Kerns-Kwi	1963 VIII	X	1961		8,6	
Su Chin Shan I	1965	II	1961		13	Anan'yeva Sitarskiy
Su Chin Shan II	1965	XII	1961	(0,4?)	11,6	Sitarskiy

There has been no careful study of the convergences with Jupiter of the comets 1951 IX Harrington-Wilson, 1952 II Harrington, 1954 XIII Harrington-Abel, and also the comets of 1963 to 1965.

Above all we cannot ignore the fact that the moments of convergences of the new and relatively bright comets are not distributed equally but are grouped near certain eras, which does not correspond to the laws of chance. These eras or periods of "convergences" are as follows (the number of the new comets is shown in parentheses): 1763-1767 (2); 1811-1817 (4 or 3, if we exclude the convergence of the comet Faye in 1816); 1840-1842 (3 or 4, if we include the convergence of the comet Faye in 1841); 1851-1853 (2); 1875 (2); 1881-1888 (4); 1898 (1); 1912-1917 (2); 1922-1926 (2); 1932-1937 (3); 1943-1946 (3); 1961 (3). /153

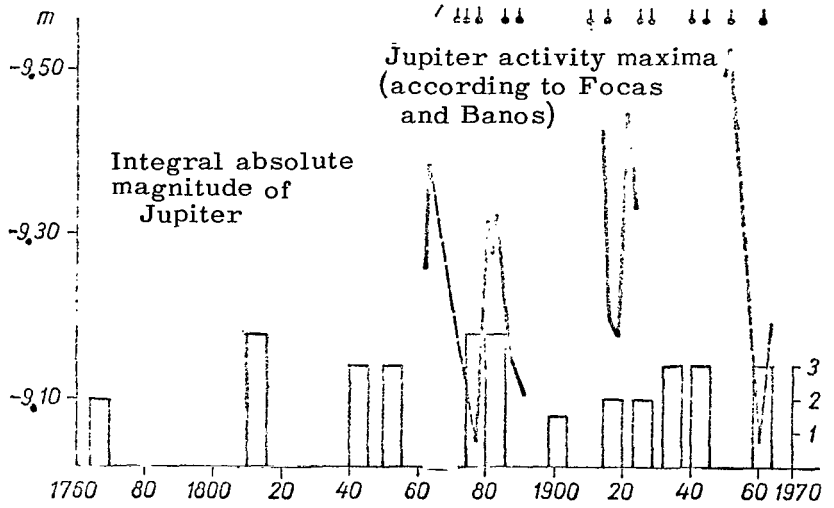


Fig. 47. Close Convergences Before the Discovery of Short Periods in Comparison to the Brightness Curve of Jupiter and the Eras of Maximum Activity on Jupiter.

Figure 47 shows clusters of approaches which characterize new short-period comets; here we also show the integral values of Jupiter (in System V) and we note the moments of activity maxima on Jupiter according to the reference of Focas and Banos [57].

We can detect a correlation between the approaches of new short-period comets to the Jupiter system and the periods of a sharp decrease in the brightness of Jupiter (as we showed the latter is related to the appearance of clouds of volcanic ash above the cloud cover of the planet). Beyond all doubt there is a connection between the flares of the Jupiter system from 1872-1888, the decrease in its brightness and the appearance of the bright comets Wolf I, Brooks II and the discovery of 4 other comets, and also between the processes on Jupiter from 1910 to 1920 and the formation of an entire series of comets divided by 10-11 year intervals.

However, even more striking are most recent events caused by /154
an immense burst of activity on Jupiter from 1961 to 1965. These activity phenomena are accompanied by a $_m$ sharp decrease in the brightness of the planet (by almost 0.4^m) as a result of the appearance of ash clouds. The activity increase which repeated the immense processes of 1872-1880 began in 1961. A dark equatorial band which formed around the planet and gradually became less and less dense was still visible in the first half of 1965 and totally disappeared toward the end of 1965. Some observational data indicate that the appearance of dust clouds around Jupiter may have been related to processes on the satellites of the planet.

New comets, 1963 VIII Kerns-Kwi, 1965 I Su Chin Shan and 1965 II Su Chin Shan, almost simultaneously emerged from the sphere of

activity of Jupiter in 1961. Such an obvious connection to processes in the Jupiter system is new and, from our point of view, positive proof of the eruptive formation of these comets. The conclusion concerning the eruptive formation of these comets can also be drawn from calculations of the probability of convergences.

We may examine two extreme cases: the probability of the transformation of the orbits from the field of parabolic comets and the problem of the approaches of short-period comets to a planet. The first problem has already been solved by H. Newton, who showed that of 10^6 parabolic comets which enter the sphere with a radius equal to the distance of Jupiter, only one can have a sufficiently close convergence and undergo significant changes in its orbit, which would be transformed from a parabola into an ellipse with $a < 6$ AU or to the corresponding hyperbola. Newton calculated that of 2670 transformed orbits there must have been 126 comets with a period of less than 6 years, 715 comets with a period of 6-12 years, 862 comets with a period of 12-18 years and 969 comets with a period of 18-24 years. The observed curve as we have seen has nothing in common with this distribution. Beginning from the Russell expression for the probability of the transformation of an orbit from a parabola to an ellipse, we obtain for comets of the Jupiter group the value of 10^{-6} which agrees fully with Newton's data. At the same time the *a posteriori* probability of the discovery of a new short-period comet with a period of up to 11 years is in fact equal to 0.16-0.18 of the total number of new comets.

The notion of the existence of a significant number of comets in the region of the motion of Jupiter and even the condensation of comets in the vicinity of giant planets is groundless. The sublimation of ices and methane-ammonia compounds must proceed up to a distance of at least 11 AU, and if we take into account the action of corpuscular solar radiation (solar wind and solar corpuscular fluxes), then sublimation must take place at a significantly greater distance. / All periodic comets which travel great distances to the freezing zone (Gale, Olbers, Coji-Stephan, Westphal, Pons-Brooks, Hershall-Rigolle and others), together indicate a systematic weakening of $1\text{-}2^m$ during the orbits. We may again point out the logical contradiction of many contemporary cosmogonists who, on the one hand, assume the possibility of condensation, and on the other hand, postulate the origin of a portion of meteors in the "asteroid zone" as a result of the "pulverization" of their surfaces due to meteoric bombardment; i.e. a process in direct contradiction to condensation.

We may now continue our elementary discussion of the problem of convergences. The mean value of a semiaxis for the orbits of Jupiter is equal to 3-6 AU. If we assume in connection with the idea of Laplace capture the existence of only parabolic velocities in the initial cometary group, then $s = (3 - 2\sqrt{2}\cos\omega)^{1/2}$ will vary within the limits of 0.45 and 2.40 (for overtaking and converging comets). There is reason to assume that all value of ω are equally probable. Assuming the mass of Jupiter to be approximately equal to 1/1000 $M_\odot$, we

have for the Jupiter family $\frac{3.6 \cdot 4}{1000} = \frac{P}{\sin \alpha} \cdot \frac{s}{\cos \phi}$, from which, starting from the maximum value of s which must correspond to $\omega = 180°$, we obtain $\frac{P}{\sin \alpha} \approx 0.006$ AU.

With the same values of the convergence parameters we can determine the orbit of the Jupiter family for the indicated limits of s, if ϕ has values from 1 to ±79.2°, which corresponds to the limiting value

$$\cos \varphi = \frac{\sqrt{3-2\sqrt{2}}}{\sqrt{3+2\sqrt{2}}}. \qquad (114)$$

But with head-on velocities which must be at least three times greater than overtaking velocities, it is more probable that there will be perijoves in the region of $\phi > 90°$, which will correspond to sharply hyperbolic heliocentric orbits. A significant number of the latter (about 50%) will approach the Sun and enter the region of visibility.

The absence of hyperbolic orbit with a significant number of equivalent ellipses of the Jupiter group of comets formed quite recently, and having a low physical stability, is indisputable proof that the Laplace capture system does not correspond to reality. But the "evolution" of the capture hypotheses by the assumption of initial elliptical or circular velocities does not save the theories. If we postulate the existence of a large number of objects in connection with the concepts of the diffusion of comets moving in the vicinity of the orbits of Jupiter and Saturn in elliptical and al- /156
most circular orbits, then the relative velocity will be equal to

$$s = \sqrt{1 + V_c^2 - 2V_c \cos \omega} \approx \sqrt{2} - \sqrt{1 - \cos \omega}. \qquad (115)$$

Approaches to a planet will take place only in cases of head-on comets, and in this case ϕ must necessarily be in the region ±(90-180°). But with these approaches there must also be an increase in the motion energy of comets and increases in the semiaxis and, in particular, the formation of hyperbolic comets. The observed characteristics of the orbits of the Jupiter system do not have anything in common with similar systems. The nature of the observed approaches contradicts any variations of the hypotheses of capture or diffusion of comets.

The total number of comets and problems of the solar system. During the lifespan of the solar system the total mass of all fragments of comets thrown from the surface of planets and moons and the remnants of meteor and meteorite matter must have reached 10^{29}-10^{31} g. This estimate which characterizes the scales of the processes of cosmic vulcanism in the solar system are in qualitative and quantitative agreement with the numerous data of planetary astronomy and the geological history of the Earth. Here we will exam-

ine only the problem of the mean density of the planets which allows us to obtain new arguments in favor of the volcanic past of the solar system. The values of the mean density are as follows: 6.1-5.8 for Mercury; 5.2 for Venus; 5.5 for the Earth; 4.1 for Mars, 1.3 for Jupiter; 0.7 g/cm^3 for Saturn.

For Mercury and Venus the values of the mean density have recently increased as a result of more precise measurements of the values of mass and the dimensions of these planets. Despite the present vagueness concerning precise values of the densities of Mercury and Venus, we may note the long-known systematic decrease in the mean density of the planets as their distance from the Sun increases. It is natural to view this as a result of the loss of atmosphere and the ejection from the planet of the less dense surface matter and volcanic gases. The speed of this process must increase as the distance of the planet from the Sun decreases, mainly as a result of the action of tide-generating forces which distort the shape of the planet and give rise to ruptures of its crust and, consequently, a more rapid course of the volcanic processes. Therefore the mean density of planetary bodies may be an important characteristic of their cosmogonical past. The high mean density of the Earth from this point of view may have been the result of additional influence from the Moon.

A quite similar behavior of the mean densities applies for the system of the moons of Jupiter (4.5 g/cm^3 for Io; 3.9 g/cm^3 for Europa; 2.3 g/cm^3 for Ganymede; 2.0 g/cm^3 for Callisto. The correlation of this important characteristic for the planets and for the moons cannot be accidental. This fact may be seen as independent /157
substantiation of the eruptive past of planetary bodies and, in addition, as evidence of the inadmissibility of the many speculative theories of cosmogony which have attempted to explain the striking sequential nature of the mean densities of the planets using various additional hypotheses.

It follows from these facts that in the initial period of their existence, all planetary bodies must have had approximately identical densities, apparently close to the density of Jupiter or the Sun (1.4 g/cm^3). Further evolution, naturally, depended on the initial mass of the planet and on the presence of close perturbing bodies. Because of the high force of gravity on the surface which prevented the disintegration of the matter of the planet and the dissipation of the atmosphere, the mean density of Jupiter did not vary significantly. A study of the processes on the surface of Jupiter directly indicates that the disrupted matter returned to the surface of the planet. Apparently rather long ago the Moon acquired a solid crust which has successfully resisted the stored activity of destructive forces (volcanic gases). The low mean density of Saturn is undoubtedly related to the particularly high level of eruptive activity and is a consequence of the massive cataclysms which led to the formations of the rings.

Assuming in the form of a first approximation the initial density distribution in the body of the protoplanets corresponding to the expression

$$\rho = \rho_0 \left[1 - \xi \left(\frac{r}{r_0}\right)^{\lambda}\right] \qquad (116)$$

(r_0 is the initial radius), we can estimate the amount of matter lost by the planets[17].

V.G. Fesenkov showed that with a value of $\xi = 0.96$, this expression satisfies the data for Jupiter; the value $\xi = 0.76$ with $\lambda = 2$ corresponds well to the condition of the Earth.

With the established configurations of the protoplanets the central densities may have been rather close. Assuming that the contemporary conditions on Earth reflect its protoplanetary state and that the central density has been roughly sustained we can ascertain whether these conditions hold for the other large planets.

/158

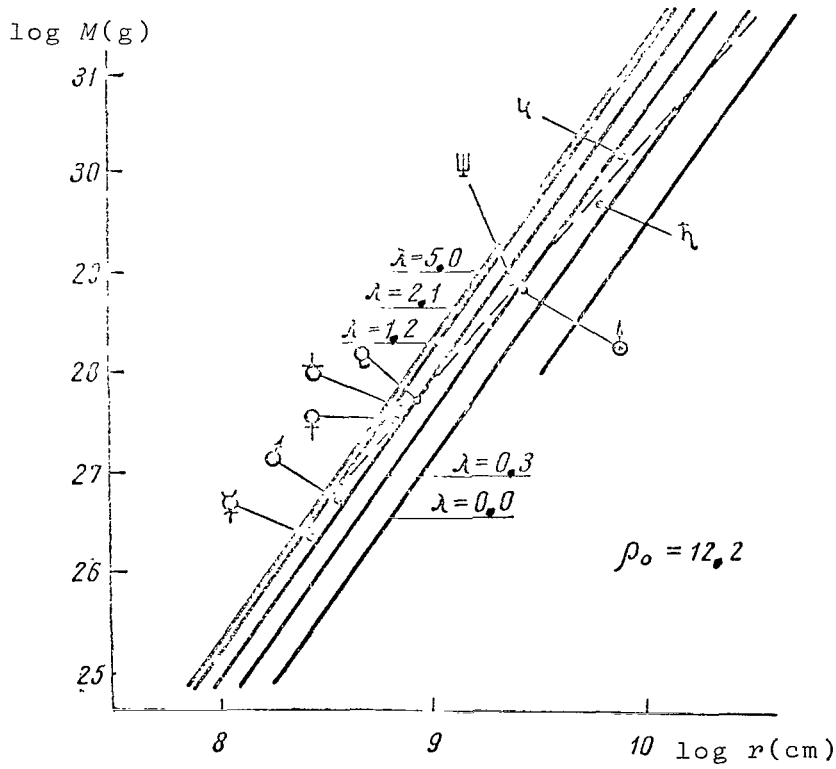


Fig. 48. A Possible Course of the Eruptive Evolution of the Planets; the Ratio of Their Mass and Dimensions.

[17]In actuality, the density will depend on the state of the central regions of the planet which possibly hold... (*Footnote continues*)

In the graph (Fig. 48) with axis log r and log M, where

$$M = 4\pi\rho_0 \int_0^{r_0} \left[1 - \xi\left(\frac{r}{r_0}\right)^{\lambda}\right] r^2\, dr = 4\pi\rho_0 r_0^3 \left(\frac{1}{3} - \xi\frac{1}{\lambda+3}\right), \qquad (117)$$

shows the series of configurations for $\xi = 0.96$ and $\xi = 0.80$ with values of λ within the limits from 0 to 5. In this case ρ_0 is taken to be equal to 12.2 (as certain geophysicists assume for the Earth).

The positions of the planets on the graph shows that Mercury, Venus, Earth and Mars correspond well to the sequence for $\xi = 0.80$ and $\lambda = 1.7$; the Moon is also located near the continuation of this series. To a certain extent, all this substantiates the hypothesis that in the protoplanetary stage the planets may have been more massive bodies with a mean density somewhat greater than unity. /159

The giant planets are located near the sequence corresponding to $\xi = 0.96$ and $\lambda = 0.3$. On the whole, they also satisfactorily correspond to one group of configurations with a given central density. Only Saturn is sharply distinguished by its extremely large dimensions which indicate the existence of an expecially extended atmosphere maintained by an internal energy flux. Although the actual values of the central density may be different from those which we assumed, nonetheless we can draw the conclusion that the inner planets, as well as Uranus and Neptune, since the time of the protoplanetary stage may have lost mass on the order of 10^{29}-10^{30} g. The total loss may have reached even 10^{31} g.

These losses of surface matter of the planets are in close correlation with the estimate of the total mass of comets and other small bodies which supports the overall disruption theory.

A large portion of this matter in the form of gases, cosmic dust (volcanic ash) and in the form of meteoric and cometary masses is ejected from the solar system into galactic interstellar space. As we can see, the total amount may be 10^{-3}-10^{-2} of the mass of the Sun in the present state. Consequently every other stellar system of the galaxy which has planets could be the same kind of source of interstellar dust and cometary gases; i.e., dispersed planetary matter.

These arguments allow us to believe that total amount the dispersed matter in our galaxy and in other galaxies may have been a result of the evolution of planets; i.e., a subsequent stage in the conversion and decay of stellar matter. The total amount of dust and gas in the galaxy does not contradict this conclusion. In any case, this important conclusion of cometary astronomy merits a study of

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(Footnote continued from preceding page) ...the planet in the "stellar" phase, on the ever-increasing gas pressure stored in the subcortical layer and, of course, on the initial mass.

all aspects. We should not exclude the possibility that from an examination of the characteristics of dispersed matter both in our stellar system and in other galaxies, we can gain an even more complete understanding of that stage of stellar matter which we call planetary.

Finally, we may enumerate other important problems which require work in relation to the radical restructuring of our representations of the nature of the planets and processes in the solar system based on the disruption concept.

We need a rapid and many-sided increase in our survey of the surfaces of the planets and moons in the visual, photographic, ultraviolet and radio areas in order to study variations and to estimate their scales.

An important problem is the examination of all cases of the approaches of short-period and periodic comets to the Jupiter and Saturn systems, taking into account influences (reactive effects, /160
corpuscular fluxes, nuclear decay and the decrease in the mass of comets, magnetic fields, the Pointing-Robertson effects and others) which may affect the motion of comets and also clarification of the evolution rate of meteoric matter in the solar system with an examination of not only perturbations, particle collision, the effects of radiational deceleration, but also corpuscular bombardment.

We also need studies of variations in the dynamic characteristics of the solar system with appreciable losses of mass by the planetary bodies which arise cyclically and the determination of its previous history.

We also need to review on a new basis the important geological and geophysical problems to establish periodization of the activity processes on the Earth, clarification of the actual history of mountain formation, polar migration, ice ages and the origin of petroleum, natural gas and coal seams.

The development of geology on new principles will be an important practical application of the results of the disruption theory. We have every reason to assume that the increases in volcanic activity on our planet are accompanied by periodic extended glaciations which are a consequence of the cloudiness of the atmosphere and a change in its chemical composition. The moving force of the possible volcanic processes must have been gas formed under the crust or in even deeper layers of the Earth.

In connection with this it is necessary to construct a theory of the internal structure of planets which lose the lighter components (gas, formed in the internal regions and dispersed material) from under a hard shell which prevents the release of energy from the inner regions of the planet and under which gaseous products of internal activity are stored.

In the next section we will deal briefly with these geological aspects of the disruption theory.

22. Scales of Vulcanism on the Earth and Geological Problems

The ejection of large masses from planetary bodies must have been accompanied by significant variations in their surface layers, decreases in their volumes and variations in the characteristics of their rotation and motion around the Sun.

Recently it has become more and more obvious that the meteorite hypothesis of the origin of lunar cirques may be applicable only to small shapes, and that the formation of the terrain of the lunar surface may be related only to internal volcanic processes. This is indicated not only by the results of "geological" study of the lunar surface (Spar, Khabakov) but also by the conclusions of a detailed statistical analysis (N. Bonev) and by the observations of N.A. Kozyreva, by the historical photographs obtained by Luniks IX and XII and by the Surveyor probe. /16

We can estimate a minimum value of the energy of a specific cataclysm by computing, for example, the work required to lift the material of the ridges of lunar craters.

The volume of the ridge of the crater Copernicus (the diameter of the crater is 103 km, the average width of the ridge is 20-25 km; the height is 5-6 km) is no less than 18,000 km^3. This corresponds to a mass of $3.6 \cdot 10^{19}$ g raised over the lunar surface on the average to a height on the order of 3 km. The acceleration of the force of gravity on the Moon is $g_m = 1.62$ m/sec^2. Thus the energy of ejection must be on the order of $2 \cdot 10^{27}$ erg.

Doubtless the total energy of disruption (taking into account the ejection of gas, ash particles, etc.) must be an order of magnitude or several orders of magnitude higher. The gigantic lunar craters may have been formed by processes whose energy reached 10^{30} erg or an even higher value. But this value significantly exceeds the energy of contemporary volcanic disruptions on the Earth and in order of magnitude corresponds to that required for the formation of cometary, meteoritic and asteroid masses in the solar system.

Even more vast must have been the processes which led to the appearance of certain moons of the giant planets or the formation of the rings of Saturn. We have every reason to assume that the ring is the result of numerous processes of the ejection of fragments of the crust of the planet, ash and ice, or surface fragments of the crust and frozen atmosphere of the moons of Saturn. Since the mass of the ring is estimated at 1/4 of the mass of the Moon, then the total energy expended on its formation must have been no less than 10^{37} erg.

The white spots on Saturn also indicate the appearances of enormous forces. We may assume that these white spots represent the ejection into the highest layers of the atmosphere of large quantities of pulverized volcanic matter (gas, ash, sand) which form a stable cloud cover and high dust content of the atmosphere.

The data of geological history of the Earth substantiate the vast nature of the volcanic processes in the history of our planet.

The shift in the Earth's poles, which has reached values of several tens of degrees [58], can be explained only as the result of catastrophes of cosmic character undergone by the Earth.

Additional proof of the high level of past volcanic processes is the strata of mineral ashes and other products of volcanic activity which are found at almost every location on the surface of the Earth. This indicates that there were periods in the history of the Earth when volcanic phenomena were of planetary nature.

In the Ukraine and Moldavia, scientists have found ash strata /162
of Tertiary or post-Tertiary periods which, as was shown by physical mineralogical investigation, may have pertained to volcanos of the Transcaucasian center. The thickness of the layer in its present compressed state in the Zaporazhian region of the Ukraine is on the order to 1.6 m, and in the Belgorod region of the former Izmaylov the thickness is 0.8-0.3 m. Using these data we may attempt to estimate the total quantity of ash materials ejected during the given period of volcanic activity. The center is assumed to be in Transcaucasia.

We may assume that the thickness of the layer can be represented by the expression

$$h = h_0 e^{-ax^2}, \tag{118}$$

where h_0 and a are parameters, x is the distance from the volcano center.

Then for our case we may assume that x_1 = 1000 km, h_1 = 2 m and x_2 = 2000 km, h_2 = 0.5 m. Starting from these values, we find that $h_0 = 0.23 \cdot 10^{-6}$ km. Then expression (118) will take the form:

$$h = 0{,}00252\ e^{-0{,}23 \cdot 10^{-6} x^2}\ (\text{км}). \tag{118'}$$

A unit volume of the strata is given by the expression:

$$2\pi h R \sin \frac{x}{R} \cdot dx \approx 2\pi h\, x\, dx$$

and the volume of the ash material is given by the expression:

$$S = 2\pi h_0 \int_0^R e^{-ax^2} dx. \tag{119}$$

In our example S = 34,000 km^3.

Other approximating methods (for example, representation as the surface of a cone) yield the same order of magnitude for the value of S.

Thus we reach the conclusion that during some single period of the disruptions in the Tertiary or post-Tertiary epoch the Transcaucasion volcanoes ejected dispersed material with a mass on the order of 10^{19} g.

This estimate refers only to ash particles and does not include a significantly larger quantity of volcanic gas and possible lava flows which also emerged from the subcortical layer of the Earth. A mass on the order of 10^{20} g with a volume of tens of thousands of cubic kilometers characterized the losses of gas and fluid material from the subcortical regions of the Earth during a single volcanic cataclysm of the Tertiary or post-Tertiary period. We know of massive lava flows of even earlier periods in the Earth's history. /163

The scales of these terrestrial processes (the energy is 10^{29}-10^{30} erg) agree fully with the cosmic volcanic processes which must have given rise to past parabolic comets and which at the present time give rise to short-period comets and meteor showers.

The ejection of masses of dispersed material and gas with a volume of tens of hundreds of thousands of cubic kilometers must have led to very important consequences and, possibly, even to radical changes in the state of the planet. We will now enumerate these consequences.

(a) Decrease in Moment of Inertia of the Planet and Its Total Rotational Energy. With a mass loss on the order of 10^{20} g, the change in the moment of inertia will be not less than 10^{-7}-10^{-8} of its value for a planet such as the Earth; i.e., on the order of 10^{37} to 10^{38} g/cm . Depending on the position of the disruption center on the surface and the initial disruption rate, the ejection into interplanetary space of even 10^{9}-10^{10} g yields a loss of 10^{-9}-10^{-8} of the rotational energy. In this case we are not taking into account the influence of gradual processes which may lead to the same value for the change in the moment of inertia.

(b) The Change in the Rotation Period of the Planet. The ejection of vast quantities of matter from the surface of the planet and the related total loss of rotational energy must lead to a decrease in the rotation period. Apparently this also explains the decrease in the rotation rate of the Moon through the massive volcanic disruption processes and possibly the decrease in the rotation rates of Mercury and Venus.

Since $\frac{dP}{P} = -\frac{dE}{2E}$ (where E is the energy, P is the rotation period), then with $\frac{dE}{E} = 10^{-5}$ (the ejection into interplanetary space of a mass

of 10^{20}g) the rotation period increases by one second (for the Earth).

This increase in the rotation period will be even greater if the direction of the ejection coincides with the direction of the rotation rate and the reactive force of the disruption provides additional braking action on the rotation of the planet.

However, the ejection of mass is accompanied by a change in the radius (20 cm for the Earth). If the decrease in the radius of the outer surface of the planet with volcanic disruptions takes place mainly due to the escape of gas, then in a certain stage of the development of the planet there will be a possible increase in the angular rotation rate, i.e., a decrease in the rotation rate by the same relative value. This will take place in the case where after the period of ejections, a gradual settling of the crust of the planet occurs as a result of the filling in of the cavities which were formed. /164

During the period of relative dormancy of volcanic activity, when the tectonic processes indicate a prolonged sinking of the crust, an increase in the rotation rate of the Earth may also be a consequence of the decrease in the mean radius.

(c) Change in the Position of the Axis of Rotation and the Shape of the Planet. The powerful volcanic ejections must have led to significant changes in the position of the axis of rotation, and apparently they were the cause of migration of the poles along the surface of the Earth as indicated by geological data.

The motion of the pole can be represented by the equations:

$$\left.\begin{aligned}
&\frac{dl}{dt}+\frac{n}{\tau}m=\frac{1}{A_0}\left[-fn+\frac{dL_x}{dt}+L_y-\frac{1}{n}\frac{dL_y}{dt}\right];\\
&\frac{dm}{dt}-\frac{n}{\tau}l=\frac{1}{A_0}\left[gn+\frac{df}{dt}-L_x-\frac{1}{n}\frac{dL_y}{dt}\right];\\
&\tau=-\frac{A_0}{C_0-A_0};
\end{aligned}\right\}\qquad(120)$$

where C_0 and A_0 are the main moments of inertia of a hard planet; L_x and L_y are the moments of momentum of the ejected masses relative to the respective axes:

$$l=\frac{\omega_x}{n};\quad m=\frac{\omega_y}{n};\quad n=\omega_z$$

(ω_x, ω_y and ω_z are the components of the angular velocity of the planet relative to the major inertial axes).

The unidirectionality of the ejections and the related nonuniform settling of the crust may have brought about changes in the position of the axis in the body of the planet by a significant angle. Even with $\frac{\Delta I}{I}$ = 10^{-7}-10^{-8}, there may have been a change in the posi-

tion of the axis of several seconds of an arc. Changes of several degrees must have been related to even more powerful processes. The change in the position of the axis in the body of the planet and in the period of rotation must have led to a change in its shape and to a transition to a new state of equilibrium. The change in shape undoubtedly may have entailed a significant increase in the force of volcanic processes and the formation of a prolonged period of high volcanic activity.

Under the conditions which pertained to the Earth, it is necessary to take into account also those changes in the moments of inertia which may have been caused by the shifting of vast amounts of oceanic water as a result of initial change in the position of the poles. Apparently even with insignificant changes in the poles as a result of the changed shape of the planet there may have been /165 almost instantaneous shifts of water masses and the ensuing further shifting of the poles.

(d) A Possible Reason for Volcanic Periods and Ice Ages. Changes in the shape of the planet which must have been manifested in ruptures of the crust near the new equatorial regions and compressions in other regions must have led to further increases in volcanic activity. During this period the high atmospheric dust content due to ash particles may have extended over the entire surface of the planets. There is every reason to assume that Venus is now undergoing exactly this period of high volcanic activity, which is indicated by the high dust content of its upper atmosphere, the presence of CO_2 and of a large quantity of ionized particles (condensation centers), volcanic dust and also the result of intense evaporation processes in the regions of lava seas which have not yet congealed.

With a high albedo of the clouds a comparatively small portion of the transmitted solar radiation penetrates to the hard surface of the planet. The diffusion in the atmosphere of a large amount of solar energy must have been the cause of glaciations which, as was true on Earth, covered significant areas of the near-polar regions of the planets.

(e) The Formation of Mountains and Other Formations on the Surfaces of Celestial Bodies. The ejection of masses and the formation of cavities on the subcortical layer of the planets must have led to ruptures in the crust which is possible only if the crust folds. The formation of mountain ranges was certainly a consequence of vulcanism. Geological data indicate that repeated processes of crust compression took place on a colossal scale. Depending on the thickness and strength of the crust and the viscosity of fluid subcortical masses, folding of the surface strata may have led to either mountain ranges or caldera-type formations. We could cast some light on this problem using the corresponding experiments in which we should simulate the conditions of a fluid or viscous planet which loses a large quantity of matter from under the surface crust which is characterized by particular physical-mechanical features.

If R is the radius of the planet, K is the thickness of the crust, B is the volume of ejected matter (gas and pulverized materials and also lava); V is the volume of the planet (we will assume that it has an almost spherical shape), then $V - B = \frac{4}{3}\pi R_1^3 = V_1$, where R_1 is the new mean radius of the planet; then $R_1^2 = \left(\frac{3V_1}{4\pi}\right)^{\frac{2}{3}}$.

As a result of the folding of the planet's crust the difference in the volumes which must be uplifted in the form of mountains will be:

$$H = 4\pi K(R^2 - R_1^2) \approx 3^{\frac{2}{3}}(4\pi)^{\frac{1}{3}} K \cdot \frac{2}{3} V^{-\frac{1}{3}} B \approx \frac{2B}{R} K. \qquad (121)$$ /166

Apparently due to the significant viscosity of the material adjacent to the crust of the planet, the crumbling and folding of the crust takes place near the volcanic centers. Geology has not dealt with the nature of the details to date.

As an example we will estimate the scale of the processes which must have led to the formation of the Caucasian Mountain system.

Based on isochasm maps, the extent of the mountain range is about 1500 km and its width is 180 to 160 km. The greatest altitude is Mount Elbrus (5.6 km); the average height of the mountain range is 2-4 km. The volume of the uplift may be estimated approximately assuming a trapezoidal cross section with altitude of about 3 km. This yields 580,000 km^3. In the case of a triangular cross section with altitude of 4 km we obtain a volume of 480,000 km^3.

If we know the value of M we can estimate the volume of subcortical material (gas and pulverized materials) ejected during the entire activity period of the Caucasian volcanic center (Tertiary and Quatenary epochs): $B = 2.5 \cdot 10^7$ km^3. Consequently the total mass ejected during the entire activity period of the Caucasian volcanic center may be on the order of 10^{22} to 10^{23} g. The ejection of such a significant mass must have led to noticeable changes in the shape of the planet, the position of the axis of rotation and the rotation period.

The vast processes may have become even more powerful due to the mobility of oceanic masses of water, which at the moment of the catastrophes may have caused extreme changes in the state of the planet.

The periods of vulcanism and folding of the Earth's crust were repeated over the entire geological history of the Earth. We know that the Caucasian Range was uplifted in the Quatenary period, the Apennines in the Miocene, the Carpathians in the Miocene (lower Tertiary period); the Alps at the end of the Eocene, the Pyranees

in the Eocene (Tertiary period); the Andes at the end of the Cretaceous period, in the Eocene and lower Pliocene; the Urals in the Carboniferous and Permian (the end of the Paleozoic); the Crimea in the Jurassic period (Mesozoic); the Scandinavian Range at the end of the Silurian period (Paleozoic); the Cordilleras in the Jurassic period. Remnants of mountain chains were detected in the Arctic and Pacific Oceans, on the bottom of the Caspian Sea, etc., apparently belonging to an even earlier period.

We must conclude from all these arguments that the contemporary characteristics of tectonics and the existence of geosynclines are phenomena remaining after the Earth's crust achieved an equilibrium state after the last period of vulcanism and changes in the surface layers of the Earth. Therefore, abrupt changes in the angular velocity of the Earth (1864, 1876, 1896 and 1940) must have /167
been related to post-volcanic processes or to overall changes in the level of shields and platforms.

We cannot exclude the possibility of the following explanation: change in the rotation rate of the Earth may have been caused by internal processes of the preparation of volcanic disruptions; for example, the storage in certain regions of the subcortical layer of vast amounts of volcanic gas. The collection of gas bubbles may have led to a temporary increase in the dimensions of the planet and rupture in its crust and also significantly changed the moment of inertia of the Earth.

The formation of volcanic cones and the folding of the crust (mountain formation) after the ejection of a sufficient quantity of gases and pulverized material is not the only mechanism for attaining equilibrium after volcanic catastrophes. The conditions on the Earth in the last epoch correspond to particular physical-mechanical properties of the Earth's crust. Its characteristics are its very high heterogeneity, the existence of shields and platforms which can be seen only as the consequence of vast past catastrophes.

However, during an earlier stage in the development of the planet with a high homogeneity on its surface and a lower thickness of the crust, the folding of the crust may have been manifested in other forms. The characteristics of the large lunar craters indicate another possibility of sinks with the formation of rings (elliptical or circular) and mountains. Apparently the course of the studies of the shapes of crust folding allows us subsequently to trace the basic stages in the development of various planetary bodies.

The above discussion indicates the urgent need for a detailed study from a modern point of view of the most vast volcanic disruptions of the past and the formulation of a new theory of the internal structure of planets and two- and even three-phase systems.

APPENDIX

BRIEF EXTRACTS FROM THE STUDIES OF THE PIONEERS OF THE DISRUPTION THEORY

"The ingenious hypothesis which Olbers proposed in order to /168
explain the smallness of the four new planets and the similarities in their distances from the Sun is well known. It assumes that these planets are none other than fragments of one large planet...

"Despite its unique qualities, Olbers' hypothesis is not deprived of probability. It follows from observations and investigations (Saussure, Daeomieu, etc.) of the structure of mountains that the Earth has borne great catastrophes and that the strata forming the crust have been crumpled, broken and moved by the effect of an internal fire or of other elastic fluids embedded in the ground; it is possible that very large pieces were broken away and thrown out...

"In this 'Système du Monde', Laplace set forth the clever hypothesis that the planets were formed from the atmosphere of the Sun; however, this explains only the spherical or nearly spherical orbits and the movements in the same direction. If this is added to the hypothesis of the eruption of planets from the effect of thermogen converting from a gaseous to a solid state inside them, then we will obtain a complete hypothesis on the origin of the entire planetary system, a hypothesis which agrees more with the nature and the laws of mechanics than all the explanations which have been set forth to this time."

J.-L. Lagrange. Surl'origine des comètes (On the Origin of Comets). Conn. de Temps pour 1814 (1812); Mécanique Analytique, Vol. II.

"The existence of comet families of the giant planets, which can hardly be explained on the basis of assumptions (on the capture), shows that masses of matter were ejected from the giant planets by eruptions similar to those which occur on the Sun .

"It is completely possible that Jupiter and Saturn threw out matter from time to time at such velocities that it withdrew completely, never returning to them."

R.A. Proctor. Comet Families of the Giant Planets. Knowledge, Vol. VI, No. 5, July, 1884.

"It is clear...that the origin of comets with explicitly parabolic paths should be sought in our own system; this is even more valid for comets with orbits of an elliptical nature ... The late Proctor was an empassioned defender of the opinion that the large /169
planets are the real sources of those planet families which are adjacent to them.

"Even on the Earth we sometimes have extremely powerful volcanic eruptions ... It is much easier to agree with this assumption than with that which leads to the hypothesis that a comet came from regions outside the planetary system, and was merely captured by the planet; for this, the comet should have been sufficiently small and compact for all its parts to undergo identical perturbations, but an extremely close convergence is needed for the comet to be captured ... I conclude from all of this that the hypothesis of the planetary origin of comets with short periods merits attention, and not the disregard with which some astronomers treat it."

A.C.D. Crommelin. The Origin and Nature of Comets. Science, Vol. XIV, Part 2, July, 1910. Russian Translation: Uspekhi Astronomii, Odessa, 1914.

"I hail S. Vsekhsvyatskiy, who supported, in the May issue of Observatory, the opinion that short-period comets were ejected by large planets, and not captured by them. I have repeatedly expressed similar ideas. I hope that this study will make the defenders of the capture theory answer the arguments which he gave against it."

A.C.D. Crommelin. Comet Notes. Observatory, Vol. 55, No. 697, p. 183, June 1932.

"The presence of incandescent magma at some level inside the Earth, volcanoes, hot sources, yields of hot gases...all this shows that there was a time when all the matter of the Earth was in a burning and melted state...

...One of the following stages in the development of the Earth probably was that, or similar to that, which the Moon imprinted on its surface, the Moon which has no ocean waters or beds of stratified sedimentary rocks and which shows on its surface a wondrous picture of the work of internal volcanic forces."

Academician A.P. Pavlov. Geologicheskaya istoriya yevropeyskikh zemel' i morey v svyazi s istoriyeye iskopayemogo cheloveka (The Geological

History of European Lands and Seas in Connection with the History of Fossil Man). Moscow-Leningrad, Academy of Sciences of the U.S.S.R. Press, 1936, p. 26.

"It can be assumed with great certainty that even the historic eruptions could have ejected matter at the Earth's highest permissible velocity...

"... if the existence of such velocities for terrestrial volcanics can be assumed to be permissible, even highly probable, at the present, then, even for the Tertiary Period, not to speak of the Carboniferous periods or even the Early Paleozoic Era, particularly the Pre-Cambrian Period, the existence of these limit velocities becomes completely obvious...

"...in his hypothesis on the formation of comets from eruptions on planets, the astronomer S.K. Vsekhsvyatskiy...argued on the possibility of the velocities necessary for this...I have an authoritative ally in this astronomer (also see Deyeske, 1919) and an even stronger formulation in favor of my ideas on the origin of meteorities at our Soviet conference on theoretical astronomy and celestial mechanics (May 1935), showing that serious attention should be given to the development of the problems (of the origin of comets and asteroids) connected with the disruption theory which was proposed by S.K. Vsekhsvyatskiy. Thus, we in the Soviet Union have almost started to work out volcanic hypotheses for the origin of comets and meteorites at the same time: one, an astronomer with regard for the objects which are of greatest interest in astronomy, and the other a petrologist with regard for the astronomical objects which are closest to geology; naturally, this coincidence will also give great strength to both hypotheses". /170

V.N. Lodochnikov. Nekotoryye voprosy, svyazannyye s magmoy, dayushchey bazal'tovyye porody (Some Problems Connected with the Magna Yielding Basalt Rocks). Leningrad, Zapiski Vserossiyskogo Mineralogicheskogo Obshchestva, Vol. 68, Nos. 2 and 3, pp. 430-435, 1939.

SOME FACTS FROM DISCUSSIONS ON THE PROBLEMS OF COMETS

1. Astronomicheskiy Tsirkulyar, No. 108, December 27, 1950.
To the Editor of Astronomicheskiy Tsirkular

Having acquainted myself with the resolutions of the expanded plenum of the Commission on Comets and Meteors (March 24-25, 1950), in the development and acceptance of which I could not take part, I beg you to publish this letter of mine.

As a member of the Commission on Comets and Meteors, I must say that the results in the section treating the disruption "hypotheses" are completely unsatisfactory, and do not correspond to the real state of affairs. Without giving the characteristics of the present state of the problem on the origin of comets, passing over the principal problems and over-emphasizing the secondary ones, the resolution shows the disruption theory in a false, distored form.

Nothing is mentioned in the resolution of the groundlessness of the capture hypothesis, of the short lifespan of comets, while this proof is the principal part of the disruption theory. The idea of an eruption is the alternative to the capture concept, and sets forth many ideas which follow from the true facts on cometary, meteoric and planetary astronomy. Only the disruption theory can explain the absence of retrograde motion in the system of short-period comets and the substantial inclinations in the orbits. Only here is the close affinity in the chemical nature of the comets and the atmospheres of planets and satellites explained.

Merely mentioning the "underdevelopment" of the disruption theory, and the fact that it "has no defenders", and not mentioning a word about the importance of this aspect, the resolution contradicts objective truth and incorrectly orients Soviet astronomy. The disruption theory has recently shown the discrepancies in the arguments set forth against it by Corlin, Kamenskiy, Bobrovnikoff and others. It has been shown that the initial velocities on the surfaces of planetary bodies should not reach values of hundreds of kilometers per second, as Corlin assumed, and which Kamenskiy and Bovrovnikoff used as their principal argument against the disruption theory; the absence of "zero" convergences has been shown, and the complete fruitlessness of attempts at connecting comets with permanent formations has been proven (Astron. Zhur., Vol. 25, p. 256, 1948; Vol. 27, p. 15, 1950)...

The disruption theory is still not generally accepted mainly because it requires a complete change in our ideas on the actual state of the planets and planetary bodies in the solar system. An analysis of different aspects of this problem is needed, particularly with the problems of volcanism, both in the past (the Moon) and in the present. Shifting logically from the data on comets, the concepts of the disruption theory should be combined with the problems

of comets, meteorites and meteoric dust, the problems of the planets, on the basis of our ideas concerning the development of planetary bodies...

The most recent discoveries in the system of short-period comets (Comets 1948i, 1948e, 1949d, 1949e of P. Shayne, with low-eccentricity orbits, converging with Jupiter ½-2½ revolutions before discovery), the subsequent development of the idea of gradually expended "reserves" of complex compounds in a frozen state in comets, and the achievements of cometary spectroscopy favor the concepts of the disruption theory and are approaching a real solution to the problem of comets. /171

S.K. Vsekhsvyatskiy

2. Astronomicheskiy Tsirkulyar, No. 163, August 12, 1955.
Letter to the Editor

"There was an article by P.G. Dukhnovskiy in the recent issue No. 6 of 'Publikatsii Kiyevskoy Astronomicheskoy Observatorii' ...entitled "On the Elements of Orbits in the Disruption Theory'; some aspects of this study compel me to make the following comments.

The author states that I did not work out the spatial problem of the disruption theory; this is not true, since I examined the spatial case in 1934 and obtained conclusions favoring the disruption theory. The ignorance of this author and the editors is even more strange in that, in his celebrated study on the origin of comets, Woerkom commented in his presentation of the results of this very study that he was 'in agreement with Vsekhsvyatskiy, that almost all the characteristics of short-period comets can be explained in this respect'.

...I find it necessary to mention the principal problem of the article, the conclusion on the distribution of the elements of heliocentric orbits and their comparison with the distributions observed. P.G. Dukhnovskiy does not mention how the theoretical distributions were calculated; however, it is clear from the article that a completely erroneous procedure was used. The elements of the heliocentric orbits were calculated only for two values of the initial velocity (58.0 and 59.0 km/sec) in dependence on the planetographic coordinates. The calculations of the number of cases in the corresponding ranges of the elements were carried out only for two of this velocity values. Since the resultant perihelion distances q at 58 km/sec were greater than 2 and eliminated from the calculations in correspondence with the rule of considering observational selection, Dukhnovskiy included in his distribution over q only the orbits for a velocity of 59 km/sec. That is why the theoretical distribution by q in the article was completely different from that observed.

This would not have occurred if the data for the intermediate velocity values (for example, 58.1, 58.2, etc.) were also used. The distributions of other elements in this article are also erroneous, but they could not be in essence quite as distorted as the distribution over q; despite the author's objective, they confirm the conclusions which were drawn long ago, that there is a striking correspondence in the kinematic picture for the disruption theory with the characteristics observed in short-period and long-period orbits.

Thus, all the conclusions in the article of P.G. Dukhnovskiy and his statement on the 'groundlessness of the disruption hypothesis' are a misunderstanding."

Kiev University, Department of Astronomy

Professor S.K. Vsekhsvyatskiy

3. To the Academic Council of the Main Astronomical Observatory of the Academy of Sciences of the U.S.S.R.

Remarks on the author's abstract of the doctoral dissertation of K.A. Shteyns treating the "Evolution of the Orbits of Comets".

"It is stated on page 3 of the author's abstract that the dissertation concerns the 'study of the structure of comets and the processes in cometary nuclei, a determination of the elements of the orbits, the perturbations from stars and large planets, an investigation of disintegration, the conditions for discovery, etc.' However, this is in contradiction with the contents of the author's abstract and the cited studies of K.A. Shteyns, which do not touch on the problems of the structure of comets and the processes in /172
cometary nuclei, do not concern a determination of the elements of the orbits, do not study the problems of disintegration or the conditions for discovery...

It is written on page 4 that, 'in the hypothesis of the formation of the solar system, in the hypothesis of the eruption of a hypothetical planet and in the hypothesis of disruption, the replacement of comets with low q can be accomplished only with the aid of perturbations from stars affecting the motion of the comets'. This statement is an obvious misunderstanding and is in contradiction not only with the essence of the problem but also with the author's abstract itself where, for example (p. 15), the effects of planetary perturbations are remarked...

...The author further concludes that it is unclear which hypothesis is true - the hypothesis of Lyttleton or the hypothesis of a cloud of comets - thus contradicting what he himself wrote on the preceding page.

...It is stated in the abstract (pp.7-8) that the disintegration depends on the distance from the Sun, which is a long-known fact, established forty years ago; nevertheless, it is not mentioned how the disintegration affects the distribution of the resultant orbits, according to the author.

It is stated on page 7 of the abstract that the 'perturbations do not change the perihelion distances', while the complete opposite is obtained on page 9.

This handling of the data makes us lose confidence in all that is written on the 'first', 'second' and 'third' laws of the diffusion of comets. K.A. Shteyns writes that he established the 'third' law of diffusion, or an increase in the number of 'new' comets at low q. Actually, this is an exposition of some of the ideas given by Oort in his famous study; the data of the catalogues show that comets with low q have lower values of the semiaxes on the average (for orbits with $q \approx 0.2$ AU, $a = 130$; for orbits with q of about 1, the average $a = 150$).

The discussion of the problems of short-period comets is just as groundless. On the one hand, it is stated without any proof that at least 50% of the short-period comets arose from long-period comets by large perturbations (capture), while the directly opposite is reported a few lines below: 'it cannot be assumed that short-period comets are formed by way of the capture of near parabolic... comets'.

The 'obsolete' studies of H. Newton and other researchers in favor of the capture theory are mentioned in the abstract, but nothing is said of the classic investigations by Callandro and Tisserand, or Russell's study, while these authors confirmed the results of the remarkable mechanical analysis of the problem made by Newton. It is suggested on pages 11-14 that the absence of short-period comets with retrograde motion can be explained in terms of the absence of visible long-period comets incident 'in the effective sphere of Jupiter'. However, the author then makes his fact contradict the mathematical conditions for the problem. We know of at least three comets with sharply pronounced retrograde motion ... For 6 comets with retrograde motion out of 15 periodic comets, for Jupiter's family of short-period comets (68), we should have had no less than 20 with retrograde motion. Even the statement of the absence of retrograde motion in the Jupiter system of comets proves the groundlessness and arbitrariness of the statements in the dissertation and the discrepancies in the capture hypothesis."

June 10, 1963 Professor S.K. Vsekhsvyatskiy

4. Kometnyy Tsirkulyar Kiyevsk. Gosudarstv. Universit., September 10, 1964.

On the Problem of the Ice Nuclei of Comets

B. Yu. Levin's "The Structure of the Ice Nuclei of Comets" was published in Astronomicheskiy Zhurnal in 1962 (Vol. 39, No. 4, p. 763) and earlier in Astronomicheskiy Tsirkulyar, No. 229, for June 5, 1962, where it was stated that "in 1949 the author set forth the idea of the ice structure of the nuclei of comets"...with reference to the periodical "Priroda", No. 10, October, 1949. In a recent review study on the physics of comets by Marochnik, published in "Uspekhi Fizicheskikh Nauk" (Vol. 82, No. 2, p. 221, 1964), the problem of Whipple's model of the ice nucleus was presented in such a way that it confirmed the above-cited statement by B. Yu. Levin. /173

We find it necessary to state the following in this regard. In a study which was written in 1947 and published in July of 1948 (Astronomicheskiy Zhurnal Akademii Nauk SSSR, Vol. 25, No. 4, pp. 265-266, 1948), S. K. Vsekhsvyatskiy was the first to present arguments in favor of the idea that the gases composing the heads and tails of comets should be formed as the result of the evaporation and dissociation of ices of complex compounds found in the nuclei of comets.

This conclusion was drawn to counterbalance the generally-accepted idea of the desorption of gases from solid meteoric masses of the nucleus. The author showed that only the evaporation of ices could explain the continuous and high-energy gas flow through the head and tail of a comet, and the presence of ice in the comet itself illustrated the relations between comets and planetary bodies from the new point of view. The characteristics of the change in spectra of comets with distance from the Sun were clarified.

In 1949-1951, the problem of the ice in comets was investigated extensively in studies mainly by the American astronomer Whipple, and then in examinations by Soviet and Czechoslovakian astronomers. All these studies confirmed the preliminary conclusions of S. K. Vsekhsvyatskiy, and the existence of ice in the nuclei of comets is presently generally acknowledged. The priority of S. K. Vsekhsvyatskiy was acknowledged by the presidents of the Cometary Commission of the World-Wide Astronomical Union by Swings and Whipple and in the studies they published later.

In supplementing the cited study by S. K. Vsekhsvyatskiy, we refer to the collection "Meteoritika" (No. VII, p. 134, 1949), where it is stated in a report on the meeting of the first meteor conference on March 18, 1949 that "S. K. Vsekhsvyatskiy mentioned...that the gases forming the shell and tail of a comet are the result of the dissociation of different hydrocarbon compounds in solid state

in the comet...", as well as the report of the president of the commission on comets of the International Astronomical Union of the Xth Astronomical Congress, where Professor Swings writes: "The existence of ice in the nuclei of comets was proposed by Vsekhsvyatskiy in 1948 (Astron. Zhur., Vol. 25, p. 256, 1948), but Whipple was the first to show to what the model of the 'ice conglomerate' should be reduced". Finally, we refer to a study by F. Whipple himself, entitled "The Structure of Cometary Nuclei" (Vol. IV, series "Solnechnaya Sistema", ed. Kuiper), where it is stated: "In 1948, Veskhsvyatskiy suggested that there is solid ice in comets."

In Levin's article in "Priroda", to which he refers in his comments, which was published one and a half years after the study of S. K. Veskhsvyatskiy, we have found nothing which could be considered as any further development of the ideas and results of S. K. Vsekhsvyatskiy.

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5. Kometnyy Tsirkulyar Kiyevsk. Gosudarstv. Universit., No. 27, June 30, 1965.

Stellar Perturbations and the Origin of Comets

In the bulletin of the Institute of Theoretical Astronomy, No. 8 (111) (1964), S. G. Makover calculated the perturbations from a certain fictitious star, and the motions of a hypothetical comet, in order to show that these perturbations can change the original orbits of comets to a large extent. However, this result was well /174 known after the study by V. G. Fesenkov (Trudy Glavnoy Astrofizicheskoy Observatorii, Vol. 1, 1922) and the major investigation by Oort concerning the cloud of comets surrounding the solar system (BAN, Vol. 1, No. 408, p. 13, 1950). In 1954, remarking on the hypothesis of Oort (Astronomicheskiy Zhurnal, Vol. 31, No. 6, p. 538), I showed that close stellar passages are rather frequent and are repeated on the average during a convergence by 30,000 AU in

5 million years (at a distance of 200,000 AU in 100,000 years), thereby completely changing the extended cometary orbits.

S. G. Makover attempted to connect his calculations of the perturbations from the fictitious star and the table of convergences with the Sun for 913 stars with the problem of the origin of comets. In this regard, he called the capture hypothesis not that design which Laplace suggested in order to explain the short-period cometary orbits, but the cosmogony of Oort, although the latter suggested that the formation of the cloud of comets was not at all the result of capture, but the consequence of the disruption of a planet or processes in the protoplanetary cloud. At the same time, S. G. Makover arbitrarily attributed the disruption theory to the negation of the effect of stars on the motion of comets. Thus, the cosmogonical conclusions of S. G. Makover are a misunderstanding. The statement that "Vsekhsvyatskiy's hypothesis" is not in tune with the results of calculations of cometary orbits sounds particularly strange. We must remember that the disruption theory was derived by Lagrange, that the groundlessness of the capture theory in explanations of short-period comets was proven by Proctor, Schulhof, Crommelin and partly Tisserand, who cannot be accused of ignorance of celestial mechanics. S. G. Makover did not examine any proofs of the groundlessness of the capture theory, not wanting to bind himself to any unfounded statements.

At the same time, in supplementing many previously formulated arguments for the disruption theory, the distributions of the inclinations of orbits of comets with different return periods (577 comets to 1965) prove to be correct.

The distributions directly show that the short-period comets are "young". The minimum in the distribution near i = 100-120° should obviously be related to the relatively recent passage of the star, the effect of which could greatly increase the perihelion distances of some comets and move them beyond the visibility sphere.

SHORT-PERIOD COMETS OF THE JUPITER FAMILY

Name	P (yr.)	T (UT)	q (AU)	e	i (deg.)	Ω (deg.)	ω (deg.)	Number of Apparitions Observed
Wilson-Harrington	2,31	1949,78	1,03	0,41	2,2	278,7	91,9	1
Encke	3,23	1786,08	0,34	0,85	13,6	336,5	182,5	47
Helfenzrieder	4,51	1766,32	0,40	0,85	7,9	76,1	178,1	1
Grigg-Skjellerup	4,83	1902,50	0,75	0,74	8,6	224,5	347,6	10
Blanpain	5,10	1819,89	0,89	0,70	9,1	79,2	350,2	1
Honda-Mrkos-Pajdusakova	5,22	1948,88	0,56	0,81	13,2	233,1	184,1	3
Tempel II	5,21	1873,48	1,34	0,55	12,8	122,0	185,2	13
Du Toit II	5,28	1945,30	1,25	0,59	6,9	358,9	201,5	1
Barnard I	5,40	1884,62	1,28	0,58	5,5	6,1	301,1	1
Neujmin II	5,43	1916,19	1,34	0,57	10,5	328,0	193,8	2
Schwassmann-Wachmann III	5,43	1930,45	1,01	0,67	17,4	77,1	192,3	1
Grishov	5,41	1743,02	0,86	0,72	1,9	80,0	7,2	1
Du Toit-Neujmin-Delport	5,54	1941,55	1,31	0,58	3,3	229,6	69,3	1
Brorsen	5,57	1846,15	0,65	0,79	30,9	104,1	13,8	5
Tuttle-Giacobini-Kresak	5,48	1951,35	1,12	0,69	13,8	165,6	37,9	4
Tempel-Swift	5,48	1869,88	1,06	0,63	5,4	298,0	105,1	4
De Vico-Swift	5,46	1844,67	1,19	0,62	2,9	65,0	278,9	4
Brooks I	5,60	1886,43	1,33	0,58	12,7	54,3	175,8	1
Lexell	5,60	1770,62	0,67	0,79	1,6	133,9	224,9	1
Cullin	5,64	1939,76	1,75	0,45	4,8	137,6	292,8	1
Pons-Winnecke	5,62	1819,55	0,78	0,76	10,7	114,9	161,6	16
Tempel I	5,69	1867,39	1,56	0,51	6,4	102,3	135,1	3
Pigott	5,89	1783,88	1,46	0,55	45,1	58,0	354,6	1

(continued)

Name	P (yr.)	T (UT)	q (AU)	e	i (deg)	Ω (deg)	ω (deg)	Number of Apparitions Observed
Taylor	6,37	1916,08	1,56	0,55	15,5	114,4	354,8	1
Spitaler	6,37	1890,82	1,82	0,47	12,8	45,9	13,3	1
Harrington-Wilson	6,38	1951,83	1,66	0,52	16,4	127,8	343,0	1
Forbes	6,38	1929,48	1,53	0,56	4,6	25,8	259,5	3
d'Arrest	6,39	1851,52	1,17	0,66	13,9	149,8	174,5	11
Schwassmann-Wachmann II	6,42	1929,22	2,09	0,40	3,7	126,3	357,7	6
Perrine-Mrkos	6,44	1896,90	1,11	0,68	13,7	247,3	163,9	4
Daniel	6,48	1909,91	1,38	0,66	19,5	71,5	3,5	5
Gaicobini-Zinner	6,52	1900,91	0,93	0,73	29,8	197,4	171,1	7
Kopf	6,58	1906,33	1,70	0,52	8,7	264,3	19,7	9
Reinmuth II	6,59	1947,63	1,87	0,47	7,1	297,4	43,9	3
Barnard III	6,63	1892,94	1,43	0,59	31,3	207,3	169,9	1
Giacobini	6,65	1896,82	1,46	0,59	11,4	194,2	140,5	1
Schorr	6,71	1918,74	1,88	0,47	5,6	118,3	278,7	1
Wirtanen	6,71	1947,92	1,64	0,54	13,4	86,5	343,5	3
Finlay	6,65	1886,89	1,00	0,72	3,0	53,2	315,2	7
Su Chin Shan II	6,69	1965,09	1,48	0,50	10,6	96,2	22,6	1
Arend-Rigaux	6,71	1950,96	1,39	0,61	17,2	124,7	326,3	3
Su Chin Shan I	6,75	1965,11	1,76	0,58	6,7	287,6	203,3	1
Viella	6,77	1772,13	0,99	0,72	17,1	259,8	213,0	6
Wolf I - Kamenskiy	6,77	1884,88	1,57	0,56	25,3	207,3	172,7	10
Johnson	6,85	1949,71	2,25	0,38	13,9	118,2	206,0	2
Holmes	6,90	1892,45	2,14	0,41	20,8	332,5	14,3	4
Borelly	6,91	1905,04	1,40	0,62	30,5	77,4	352,3	7

Name	P (yr.)	T(UT)	q(AU)	e	i (deg)	Ω (deg)	ω (deg)	Number of Apparitions Observed
Harrington II.....	6.98	1953.72	1.69	0.54	11.6	136.6	219.4	2
Brooks.....	7.07	1889.75	1.95	0.47	6.1	18.8	343.6	10
Harrington-Abel.....	7.20	1954.95	1.78	0.52	16.8	145.9	338.3	2
Swift II.....	7.22	1895.64	1.30	0.65	3.0	171.6	167.8	1
Shayne-Shaldeck.....	7.28	1949.90	2.23	0.40	6.2	167.4	215.3	1
Reinmuth I.....	7.24	1928.08	1.86	0.50	8.1	125.2	8.7	5
Denning II.....	7.42	1894.11	1.15	0.70	5.5	85.1	46.3	1
Faye.....	7.44	1843.79	1.69	0.56	11.4	211.0	200.0	15
Ashbrook-Jackson.....	7.48	1948.76	2.31	0.40	12.5	2.3	348.9	3
Whipple.....	7.49	1933.58	2.50	0.35	10.2	188.8	190.5	5
Wolf-Harrington.....	7.59	1925.03	2.43	0.37	23.7	260.7	180.1	4
Metcalf.....	7.77	1906.77	1.63	0.58	14.6	195.1	200.0	1
Arend.....	7.77	1951.90	1.82	0.54	21.7	357.7	44.5	2
Oterma.....	7.89	1942.64	3.39	0.14	4.0	155.2	354.8	4
Schaumasse.....	8.07	1911.87	1.23	0.70	17.7	94.2	44.2	6
Comas-Sola.....	8.52	1927.22	1.77	0.58	13.8	65.9	38.5	5
Jackson-Neujmin.....	8.57	1936.75	1.46	0.65	13.3	164.4	197.3	1
Denning I.....	8.69	1881.70	0.72	0.83	6.9	66.8	312.6	1
Swift I.....	8.92	1889.91	1.36	0.68	10.3	331.3	69.7	1
Kerns-Kwi.....	8.95	1963.96	2.21	0.49	9.0	315.4	131.2	1
Vaisala I.....	10.58	1939.32	1.76	0.63	11.3	135.6	44.3	3
Neujmin III.....	10.90	1929.49	2.04	0.58	3.7	158.5	140.8	2
Gale.....	11.19	1927.45	1.21	0.76	11.6	67.4	209.9	2
Schwassmann-Wachmann I.	16.37	1925.35	5.48	0.15	9.4	323.1	359.3	3

COMETS OF THE SATURN FAMILY

Name	P (yr.)	T (UT)	q (AU)	e	i (deg)	Ω (deg)	ω (deg)
Clemola	10,90	1965,63	1,76	0,64	10,6	182,0	148,0
Slafter-Burnham	11,64	1958,68	2,54	0,50	8,2	346,2	44,4
Van Biesbroeck	12,41	1966,54	2,41	0,55	6,6	148,8	134,2
Wild	13,19	1960,21	1,93	0,67	19,7	359,0	166,7
Peters	13,38	1846,42	1,53	0,73	30,7	261,9	339,6
Tuttle	13,61	1939,86	1,02	0,82	54,7	269,8	207,0
Du Toit	14,79	1944,46	1,28	0,79	18,7	22,5	257,0
Perrine	16,4	1916,45	0,47	0,93	103	224	95
Neujmin I	17,97	1948,96	1,55	0,77	15,0	347,2	346,7

COMETS OF THE URANUS FAMILY

Crommelin (Pons-Coggia-Forbes)	27,9	1956,82	0,74	0,92	28,9	250,4	196,0
Tempel-Tuttle	32,9	1965,33	0,98	0,90	162,7	234,4	172,6
Stephan-Oterma	39,0	1942,96	1,60	0,86	17,9	78,6	358,4

COMETS OF THE NEPTUNE FAMILY

Westphal	61,7	1913,9	1,25	0,92	40,9	347,3	57,1
Pons-Gambard	63,8	1827,4	0,81	0,95	136,4	319,4	19,3
Ross	64,6	1884,0	0,31	0,98	114,7	265,2	137,6
Dubyago	67,0	1921,3	1,12	0,93	22,3	66,5	97,4
Brorsen-Metcalf	69,1	1919,8	0,48	0,97	19,2	311,2	129,5
Olbers	69,6	1956,5	1,18	0,93	44,5	85,4	64,6
Pons-Brooks	70,9	1954,4	0,77	0,96	74,2	255,2	199,0
De Vico	75,7	1846,2	0,66	0,96	85,1	79,0	12,9
Halley	76,0	1910,3	0,59	0,97	162,2	57,8	111,7
Vaisala II	85,3	1942,1	1,29	0,93	38,0	171,6	335,2
Swift-Tuttle	120	1862,6	0,96	0,96	113,6	138,7	152,8

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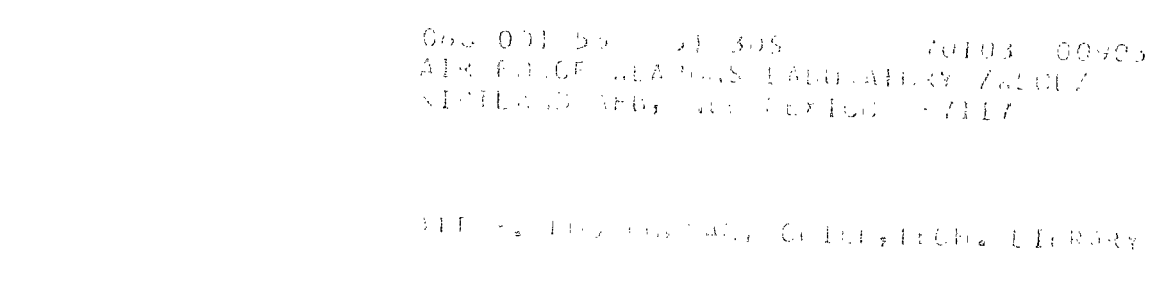

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